UNIT IV

CHAPTER 4

Energy Monitoring & Targeting, Energy Management of Electrical Systems

Syllabus

Energy Monitoring & Targeting

Defining monitoring and targeting. Elements of monitoring and Targeting. Analysis techniques for energy optimization, Cumulative Sum of Differences (CUSUM). Electricity billing.

Energy Management of Electrical Systems

Electrical load management and maximum demand control, Power factor improvement and its benefit, selection and location of capacitors, distribution and transformer losses.

Objectives

After studying the chapter you will be able to

- Understood the elements of monitoring and targeting.
- Understand analysis techniques for energy optimization
- Understand the components of tariff
- Know the electricity billing tariff structure
- Understand load management
- Know the power factor improvement and its benefits.
- Understand the selection of capacitors.

Part I: Energy Monitoring & Targeting

4.1 Introduction

- The energy used in any plant mainly varies with production processes, volumes and input.
- Energy monitoring and targeting is the activity that uses information on energy consumption as a basis for control and managing consumption downward.
- The two component activities are distinct yet inter-related:

Monitoring

- Monitoring is the regular collection of information on energy use.
- Its purpose is to establish a basis of management **control**, to determine when and why energy consumption is deviating from an established pattern, and as a basis for taking management action where necessary.
- The fundamental objective to carry out monitoring is to preserve an already established pattern.

Targeting

- Targeting is the identification of levels of energy consumption, which is desirable as a management objective to work towards energy saving.
- Monitoring and target setting have elements in common and they share much of the same information.
- As a general rule, however, monitoring comes before target setting because without monitoring you cannot know precisely where you are starting from, or decide if a target has been achieved.
- The reporting phase not only supports management control, but also provides for accountability in the relationship between performance and targets.
- In the process of M and T, the facility is systematically divided into various Energy cost centers.
- Each energy center is closely monitored for its energy consumption and the energy used is compared with production volume or any other suitable measure of operation.
- Once the information is obtained in real time, several tasks can be performed on it which includes, setting of targets, minimization and interpretation of variations and to carry out remedial actions.
- The Monitoring and Targeting programs have been so effective that they show typical reductions in annual energy costs in various industrial sectors between 5 and 20%.
- Energy monitoring can be carried out to determine the consumption of energy within the organization and hence it works as a means to develop the prerequisite information for controlling the energy consumption.
- Energy monitoring emphasizes upon both qualitative as well as quantitative information about the energy consumption.
- It is a means of obtaining qualitative information about the energy usage along with the quantitative usage.
- In order to carry out energy monitoring, one has to carry out quantitative analysis of the historical data which includes,
  - Electricity bills, which contains the information regarding the demand and consumption of electricity along with the consumption of fuel and various costs, associated with it.
  - Statistics of the energy consumption of electrical energy at various phases or steps of the process of energy consumption.
  - Major factors that influence the consumption of energy such as production, hours of operation, climatic conditions.
- Hence, energy monitoring can be briefly summarized as the technique that quantitatively relates the consumption information to the critical independent variables.

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4.2 Elements of Monitoring and Targeting

Key elements that form a proper Monitoring and Targeting system are

- **Recording**

  It refers to the measurement and recording process of energy consumption in the facility.

- **Analysis**

  It refers to the study of the relation between energy consumption with respect to the measured system output. For example: Analyzing the energy consumption by correlating it with the production quantity.

- **Comparison**

  It is the comparison of energy consumption of the system under study with the suitable reference standard or appropriate benchmarks.

- **Target setting**

  Target setting refers to the placing a target in order to minimize or regulate to limit the energy consumption.

- **Monitoring**

  Monitoring refers to the comparison of the actual energy consumption of the facility with the target set as in previous element.

- **Reporting**

  Reporting includes the documentation of the results achieved from the previous elements. It also specifies the deviation from the set target.

- **Control**

  Controlling means the execution of the remedial management measures in order to cope up with the deviations.

Also the major constituents of a particular monitoring and targeting system are :

- **Examination of the energy statements**

  It refers to the checking of the accuracy of the energy statements (energy invoices, bills, debits)

- **Energy cost allotment**

  It refers to the proper distribution of the energy costs to particular departments.

- **Energy performance**

  Discover the energy performance. (Calculate the energy efficiency)

- **Recording**

  It refers to the recording of energy usage. Recording and maintaining the same helps to observe and check the improvement in energy efficiency in the intended projects.

- ***Spot the problem***

  It emphasizes on identifying the reasons of troubles (if any) and highlight the problem or performance issue in the equipment or system under study.

4.3 Analysis Techniques for Energy Optimization

4.3.1 Data and Information Analysis

- Data and information analysis is a part of the activity of monitoring a facility, system or process.
- In this case, it should be noted that data and information have clear cut separate existence.
- Data means raw numbers obtained from various measurements.
- Information is what we get after the analysis of this data.
- After this, an action is taken on the basis of information investigation.
- For e.g. consider a production situation of a melt furnace.
- After analyzing this information obtained is increase in kWh/tonne and reason.
- Corrective action on this may be repositioning of electrode in furnace.

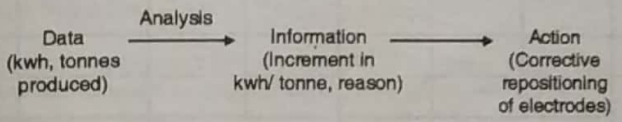
Analysis
Data (kwh, tonnes produced)
Information (Increment in kwh/ tonne, reason)
Action (Corrective repositioning of electrodes)

Fig. 4.3.1 : Data and information for a production situation

- Above figures explains the process as linear moreover it is suggested to think in terms of improvement cycle as illustrated in following figure.

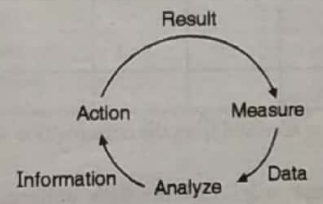

Fig. 4.3.2 : The measure - analyze action cycle

- It can be observed from the above cycle that corrective action starts a new round of data and information collection and analysis to ensure the effectiveness of changes and whether they are being sustained.
- Periodical collection and analysis of Electricity and other fuel bills is necessary.
- A format particularly used to gather plant level information is as given below.

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Table 4.3.1 : Table Annual energy cost sheet

Annual Energy Cost Sheet									
	Thermal Energy Bill				Electricity Bill				Total Energy Bill
Month	Fuel 1	Fuel 2	Fuel 3	Total Rs. Lakh	Day kWh	Night kWh	Maximum Demand	Total Rs. Lakh	Rs. Lakh
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
Sub-Total									
%									

- All sort of information can be accessed from the consumption data only if its analysis is done in a correct way.
- Electricity bills and consumption bill of other fuels utilized in plant should be collected and analyzed periodically. Consider a typical example of Annual energy cost sheet of some plant as shown in Table 4.3.1.

4.3.2 Pie Charts

After obtaining the respective annual energy cost, a pie chart (see Figure 4.3.3) can be drawn as shown below specifying percentage share of each fuel in total energy bill:

4.3.2.1 Pie Charts based on Energy Bill

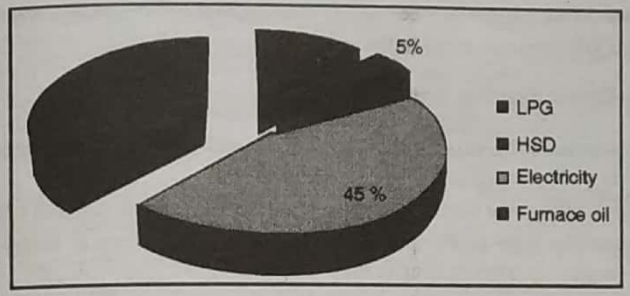

Fig. 4.3.3 : % Share of fuels based on energy bill

4.3.2.2 Pie Chart based on Energy Consumption

- Amount of each fuel consumed by the plant should be converted into common units such as kCal. Conversion factors can be observed in following table (Table 4.3.2).

Table 4.3.2 : Fuel conversion data

Energy source	Supply unit	Conversion factor to kCal
Electricity	kWh	860
HSD	kg	10,500
Furnace Oil	kg	10,200
LPG	Kg	12,000

- After conversion to a common unit, a pie chart can be drawn showing the percentage distribution of energy consumption as shown in Fig. 4.3.4.

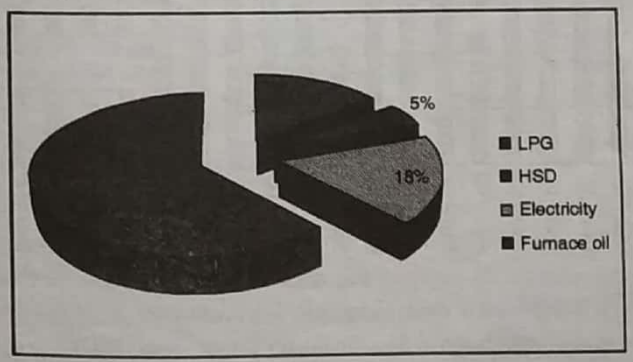

Fig. 4.3.4 : % Share of fuels based on consumption in kCals

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- To find out what exact is given on in the plant, it is crucial to deal with two key aspects :
  - Variation of energy consumption with respect to the production.
  - Change in the relation between energy consumption and production with time.
- These aspects are addressed in the following sections.

4.3.3 Energy Consumption and Production

- An important aspect of Monitoring and Targeting (M and T) is to identify the factors driving the energy consumption.
- Various factors influencing the energy consumption are Production, hours of operation, weather.
- Data collection of energy consumption, energy cost and production is followed by analysis to understand the exact process running in the plant.
- Graphically representing the data is an effective methodology to develop the relation between energy consumption and Production.
- It gives better understanding of the plant process than a mere tabulated data.
- If only energy consumption data is plotted against time (weeks, months), it does not give a detail insight into plant process.
- Hence, this plot is of limited usefulness with respect to recognition of opportunities for energy efficiency improvement and consumption control.

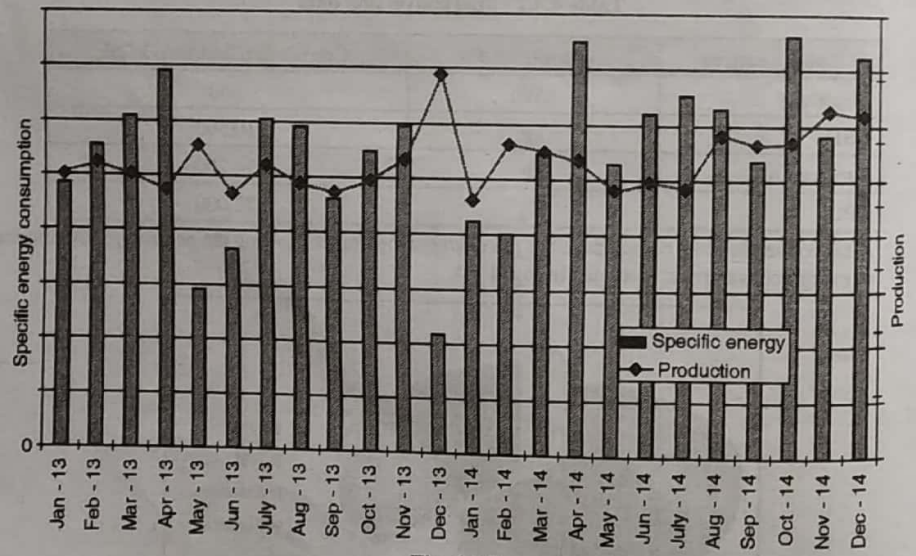

Fig. 4.3.5

- For any plant, it is important to relate energy use with production.
- It implies the need of calculation of Specific Energy consumption (SEC).
- Specific Energy consumption (SEC) is energy consumption per unit of production.
- In this case, accuracy of monitoring depends on quality of data of energy as well production.

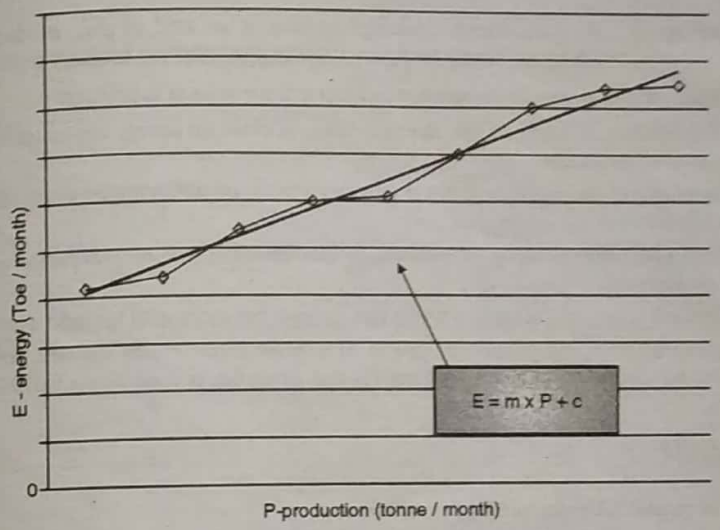

Fig. 4.3.6 : Energy Vs Production

- It's a well known fact that Specific Energy consumption (SEC) is influenced by the level of production.
- The better way to gain understanding of relation between energy and production is to plot energy against production.
- Energy is plotted on Y-axis and Production on X- axis (See Fig. 4.3.6)
- After this, Single variable analysis is carried out to add a best fit trend line on a scatter plot.
- This trend line can be used to derive a "Standard", which is used to calculate the consumption of upcoming year.
- In the accompanying graph, a low degree of scatter can be observed that implies a good fit.
- Poor fit indicates the poor level of control.
- The equation of the trend line expresses the relationship relating energy consumption with respect to production.
- Equation of Straight line,

$$y = m^*x + c$$

- Here, the equation of trend line will become,

$$\text{Energy} = \text{Slope} \times \text{Production}$$

- More specifically,

  Energy Consumed for the specified period = m x Production for the same period + c
- It gives,

$$E = m \times P + c$$

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here,

c – Intercept – Its fixed energy consumption even at no load or zero production, due to energy necessary for lighting, heating, etc required ancillary services.

m – Slope – It's an energy consumption which has a direct relation to production.

- From this equation of the trend line, the calculation of expected energy consumption is possible for any level of production.
- The importance of this equation is that it provides a basis, on which implementation of M and T system can be done.
- The fixed and variable energy consumptions can be addressed with separate and different reduction measures.
- This approach is not only suitable at whole factory level but also useful for individual process.
- Energy consumption and production data in M.S. excel sheet obtains the best possible fitting trend line by the use of X-Y chart options. (in real terms this is done single variable regression analysis)

4.3.4 CUSUM

- CUSUM means "**CU**mulative **SUM** of differences.
- These are the differences between the actual consumption and the expected consumption for the specified time.
- The expected consumption is found out on the basis of developed pattern (as seen in previous point)
- The difference between the actual consumption and established trend will be small if the consumption in the plant is following the established trend and may be positive or negative.
- In such cases, CUSUM of these differences will stay near zero over the time of process.
- CUSUM graph continues to follow the trend till some changes occur in the process being monitored.
- These changes may be due to improvement because of energy saving measures or decrement in the efficiency caused by poor control.
- The difference normally oscillates around zero and depends on fluctuation of energy consumption; it becomes less symmetrical with respect to zero if there is a change in consumption.
- Therefore, normally CUSUM graph consists of the number of kinks in it.
- Each kink refers to the change in pattern. Any straight section without kink in the CUSUM graph indicates the pattern is stable for that period.

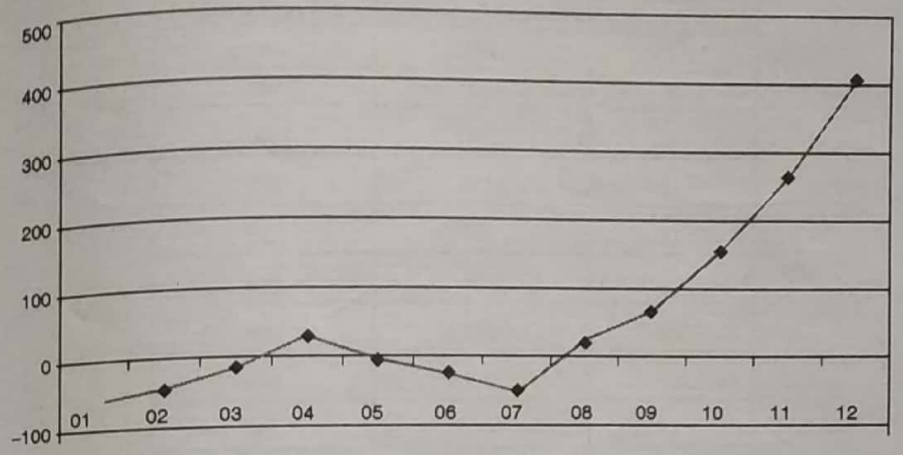

Fig. 4.3.7 : Sample CUSUM graph

- The Fig. 4.3.7 shows an example of CUSUM chart.
- Expected energy consumption is calculated using the equation derived previously.
- It can be observed in the chart that performance in the first month is better than standard, then the line going up indicates the declined performance till fourth month. Then, it's showing improvement until seventh month.
- However, after this, continuous decline in performance can be seen – shown by line going up immediately after seventh month.

4.3.4.1 Case Study on CUSUM Technique

- A data of Energy consumption and production of an industrial plant is collected over 18 months, as shown in the following table.
- Heat recovery equipment is installed in the system during the 9th month.
- Estimate the savings using monthly data of the plant by CUSUM analysis.
- Table 4.3.3 : Production and Energy Consumption (Monthly)

Month	Production – P (Tonnes / Month)	Energy – E (*Toe / Month)
1	760	680
2	880	680
3	920	760
4	1040	760
5	640	600
6	1040	800

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Month	Production – P (Tonnes / Month)	Energy – E (*Toe / Month)
7	480	560
8	1240	848
9	1200	840
10	1120	800
11	880	720
12	720	640
13	840	680
14	960	744
15	1080	760
16	560	560
17	520	560
18	1000	760

***Toe – Tonnes of oil equivalent**

4.3.4.2 Steps to Apply CUSUM Analysis

1. Plot the graph of Energy Vs Production for the first 9 months. (Refer Fig. 4.3.8)
2. Obtain the best fit Trend Line. (Refer Fig.4.3.8)
3. Derive the equation of the Trend Line. (Refer Fig. 4.3.8)
4. Calculate the Expected Energy Consumption. It is termed as E_{calc} in the following table. (Refer Table. 4.3.4)
5. Calculate the difference between actual energy consumption and calculated energy use. $E_{act} - E_{calc}$ (Refer Table 4.3.4)
6. Compute CUSUM. (Refer Table 4.3.4)
7. Plot the CUSUM chart for all 18 months (Refer Fig 4.3.9)
8. Estimate the savings collected by the installation of Heat recovery equipment.

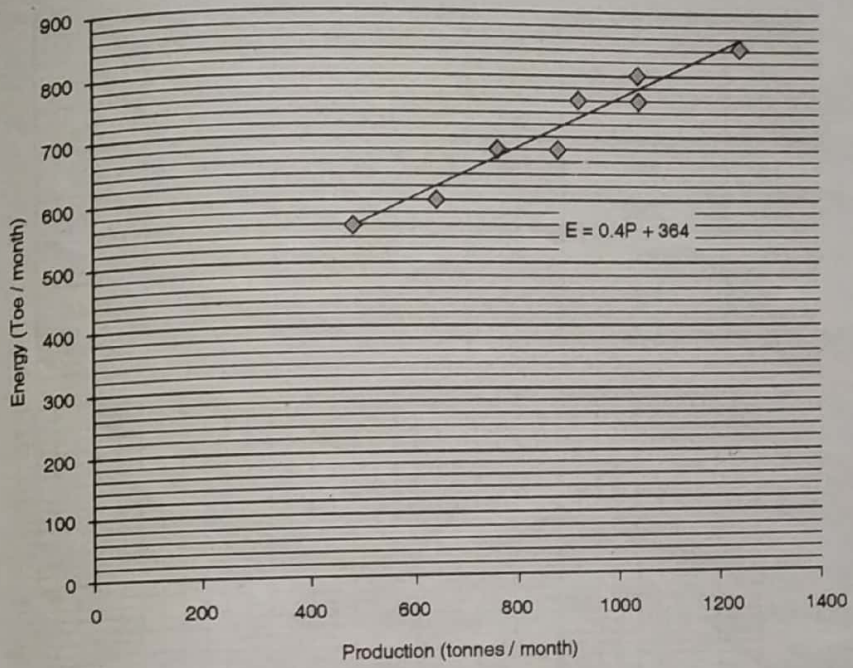

Fig. 4.3.8 : Energy Consumption Vs Production

Table 4.3.4 : CUSUM calculations

Month	Production (P)	Energy (E)	$E_{calc} = 0.4P + 364$	$E_{act} - E_{calc}$	CUSUM
1	760	680	668	12	12
2	880	680	716	– 36	– 24
3	920	760	732	28	4
4	1040	760	780	– 20	– 16
5	640	600	620	– 20	– 36
6	1040	800	780	20	– 16
7	480	560	556	4	– 12
8	1240	848	860	– 12	– 24
9	1200	840	844	– 4	– 28
10	1120	800	812	– 12	– 40
11	880	720	716	4	– 36

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Month	Production (P)	Energy (E)	$E_{calc} = 0.4P + 364$	$E_{act} - E_{calc}$	CUSUM
12	720	640	652	– 12	– 48
13	840	680	700	– 20	– 68
14	960	744	748	– 4	– 72
15	1080	760	796	– 36	– 108
16	560	560	588	– 28	– 136
17	520	560	572	– 12	– 148
18	1000	760	764	– 4	– 152

Fig. 4.3.9 : CUSUM chart for all 18 months

- As can be seen in the Fig. 4.3.9 , CUSUM oscillates around the zero line for some months and then drops sharply after the 11th month.
- It implies that, though the heat recovery equipment is installed in 9th month it took almost two months to ensure the effective operating conditions. After this month ongoing steady savings are observed.

- **Calculation of savings :**
  - On the basis of graph, Energy Saving accumulated in the last seven months is 116 Toe (Refer Table 4.3.4)

    E_{calc} in last seven months = 4820 Toe

    E_{act} in last seven months = 4704 Toe
  - Energy Saving after proper operation of heat recovery unit (in last seven months)

    = 4820 – 4704 = 116 Toe.
  - In terms of percentage, (116 / 4704) x 100 = 2.46 %
  - It shows the saving of almost 2.5 % of the energy consumption.
  - Energy manager can keep the track of plant performance and identify any possible change in trend early by regular and proficient use of CUSUM technique.

4.4 Electricity Billing

- Electricity is generated in power system, which is then delivered to large number of consumers.
- Consumer can be persuaded to use this power if it is sold at proper rates.
- Electricity bill is nothing but a **bill of an electricity consumption** by the consumer.
- Tariff literally means rates or charges for a service rendered to a consumer.
- In case of supply of an electrical power, Tariff refers to the rate at which a consumer is charged for the electrical power supplied.
- An electric supply company invests large amount in generation, transmission and distribution of electrical energy.
- Power company's source of revenue is Tariff, which obviously targets return on investment as well as recovery of operating costs.
- Even though the tariff structure of an electricity bill includes overall cost generation, delivery as well as profits yet all categories of consumers can't be charged same. This is because cost of producing electricity considerably depends upon magnitude of electrical energy consumed and load conditions of the user.
- Hence, various categories of consumers have different considerations while deciding a tariff structure for their electricity bill.
- Consumer categories are :
  - Residential
  - Commercial
  - Industrial
  - Agricultural

  Typically, the tariff codes begin with LT (low tension) or HT (High Tension).
  - **LT codes-** LT codes are used for residential connections as well as small offices.
  - **HT codes-** HT codes are used for bigger industries and complexes.
- The category of billing can be determines whether the load is residential, commercial or industrial. According to the different tariff codes, various rates or slabs can be applied for billing purpose.

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4.4.1 Components of Tariff

(a) Maximum demand Charges

These are the charges imposed for the maximum demand registered during month or specified billing period according to the rates of the utility.

(b) Energy Charges

- Units consumed specify the aggregate amount of electricity utilized over certain duration.
- These are the charges imposed for energy (Kilowatt Hours-kWh) consumption over a month or a specified billing period according to the rates of the utility.
- These are often charged in slabs of use rates.
- It is obtained from meter reading.

(c) Connected load

- Connected load is the total wattage of appliances which are being used on the sanctioned connection.
- It has an effect on the Fixed Charges for a particular connection.

(d) Fixed Charges :

It's a fixed amount of charge included in monthly electricity bill which depends on type of connection and connected load.

(e) Electricity Tax

- Some states put tax on transaction of electricity. This is often charged in percentage of total amount of bill.
- Point to be noted that government receives this amount and not the utility.

(f) Electricity Duty Charges

- Some states apply duty on supply of electricity which is often charged an additional cost per unit or may also be in percentage.
- Point to be noted that government receives this amount and not the utility.

(g) Fuel Surcharge / Fuel Adjustment Charges

- Tariff structure is set up for an year or two, Cost of generation changes every month.
- Fuel surcharge apprehends changing cost of generation.
- It is applied per unit.

(h) Power factor penalty or incentives rate

- Low power factor is an indication of inefficient use of electrical energy.
- Penalties and Incentives are imposed according to the Power Factor maintained by the consumer.

(i) Time Of Usage (ToU) Rates

- Time of Usage involves division of tariff over different duration of energy usage by consumer.
- Day, Month or Year are be divided into various tariff slots at various rates.

(j) Penalty for exceeding Contract Demand

- Contract demand is the power requirement of the consumer as agreed by the supplier while giving the connection that is not likely to be exceeded by the consumer.
- Penalties are imposed on the consumer by the utility in the billing if it exceeds.

4.4.2 Electricity Billing Tariff Structures

Different types of Electricity Billing Tariff Structures are used in practice such as:

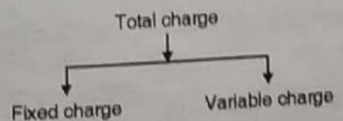
- Flat demand Tariff
- Simple Tariff
- Flat Rate Tariff
- Step Rate Tariff
- Block Rate Tariff
- Two part Tariff
- Three part Tariff

Apart from this more specific tariffs like :

- Time off Day Tariff
- Time of Use Tariff
- Power Factor Tariff
- Maximum Demand Tariff
- Each tariff structure has different calculation to calculate the total energy charge which consumer has to pay for his consumption.
- Electricity tariff can have various forms that vary from country to country as well as different markets of the same country.
- Medium and Large enterprises are categorized in High Tension Category. Electrical utility applies Two-Part tariff structure for the electricity billing of these.

Two Part Tariff

- Two part tariff is also known as Hopkinson Demand Rate.
- Total charge to be set is divided into Fixed charge and Variable charge.



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Fixed charge

- Fixed charge has nothing to do with energy consumed but it is in proportion with the maximum demand.
- Therefore, the fixed charge is set according to the maximum demand registered during month or specified billing period.
- In Two Part tariff, fixed charge attributes the recovery of
  - Interest and Depreciation on the capital investment in infrastructure and equipments.
  - Taxes and Insurance charges
- Fixed charge is a certain amount set per kW of maximum demand.

Variable charge

- Variable charge recovers Running cost or Operating cost.
- Operating cost depends upon total energy consumed and varies with energy supplied to consumer.
- Variable charge set is certain amount per kWh of energy consumed.

$$\textbf{Total charge} = \textbf{Rs.}\ (C_F \times \_\_\ \textbf{kW}) + (C_V \times \_\_\textbf{kWh})$$

Where,

C_F - Charge / kW of maximum demand assessed.

Cv - Charge / kWh of energy consumed.

- The utility installs an energy meter for the billing purpose at the consumer premises. Minimum outputs that an energy meter gives for a specified billing period are,
  - Maximum demand-

    Maximum demand is registered during a month, it is measured at a specified preset time interval. The value of maximum demand s reset at the end of every month.
  - Active Power (kWh)
  - Reactive Power (kVARh)
  - Apparent Power (kVAh)
- Most of the utilities now switched over to the latest electronics meters from the outdated electromechanical meters that has some sublime features that proves useful not only for utility but also for industries. Major of them are
  - Storage memory for data logging and recording.
  - Compliance with Time of Day Tariffs
  - Compliance with Maximum Demand measurement
  - Tamper detection
  - Measurement of Harmonics and Total Harmonic Distortion (THD)
  - Absence of moving parts

4.4.3 Discussion on Maximum Demand

- Reader should importantly note here that Maximum demand is not recorded as the instantaneous maximum demand drawn but it is the time integrated maximum instantaneous power consumed over a specified recording cycle of time.

- For e.g. in an industrial plant, demand drawn over a recording span (which is predefined) of 30 minutes are,

1. 2000 kVA for 5 minutes
2. 3200 kVA for 10 minutes
3. 4000 kVA for 7 minutes
4. 3700 kVA for 8 minutes

Then maximum Demand Recorder calculates Maximum Demand as,

$$MD = \frac{(2000 \times 5) + (3200 \times 10) + (4000 \times 7) + (3700 \times 8)}{30} = 3320\ kVA$$

- Such Demand values are recorded for a month and the highest among them is the maximum demand for that particular month.
- Next time the meter records the value of maximum demand only if it surpasses the previous maximum demand.
- Thus, industry has to pay for the highest recorded maximum demand despite of their low average value of maximum demand during the month.
- This is applicable even though it occurs for just one predefined recording span (30 minutes) here during whole month.

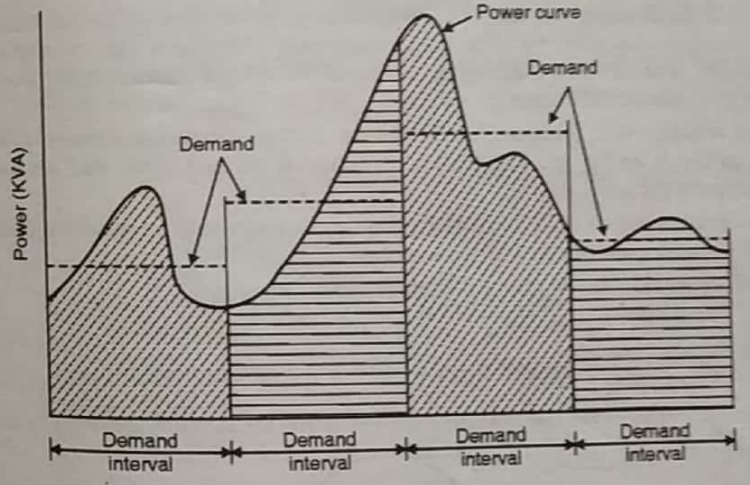

Fig. 4.4.1 : Demand Curve

- The Fig. 4.4.1 shows time to time varying demand.
- In the above Demand Curve, point to be noted are,
  - The area under horizontal dotted line is the average demand of the demand measured over the predefined recording time interval.
  - Demand for each interval = Average power over the interval.
  - Area under Dotted Line + Area under Power Curve = Total Energy for the interval.

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- The utility has to be able in every aspect to satisfy customer's energy demand. The peak consumption of the customer is an important aspect according to which utility has to build out its infrastructure. This is an important reason behind measuring and charging for the maximum demand.
- Measuring and billing for maximum demand is a way to assess the extent of the expansion of the infrastructure driven by the individual consumer needs.

Part II : Energy Management of Electrical Systems

4.5 Electrical Load Management and Maximum Demand Control

MU - May 2016

- In a greater point of view, two key points that has caused our capacity to fail to supply the electricity demand are,
  - The growth in electricity use
  - Widespread time of use diversity of end use
- As a remedial action over this, a capacity addition proves very costly and time consuming cumbersome alternative. However Load management programmes can not only considerably minimize peak demands, reducing the burden on the utility infrastructure but also encourages effective utilization of power plant capacities.
- Load management or Demand Side Management (DSM) is the process of balancing the electrical energy supply on the grid with the load by adjusting the load rather than the output energy generated at the power station.
- Load management serves as a tool for shifting the electrical energy consumption from periods of peak demands to the period of off- peak demand.
- Load management may be via any of the major three categories :
  - Load clipping
  - Load shifting and
  - Valley filling
- Some sub categories in addition to these major strategies are shown in following figures :

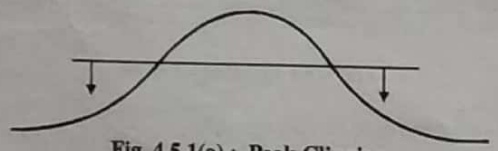

Fig. 4.5.1(a) : Peak Clipping

- **Peak Clipping** - Reduction in loads on utility during the hours of Peak demand

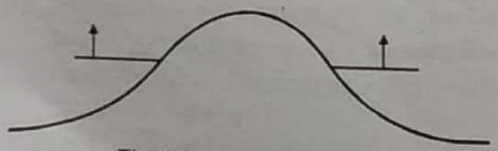

Fig. 4.5.1 (b) : Valley filling

- **Valley filling** - Build the load in Off-Peak hours to improve the load factor

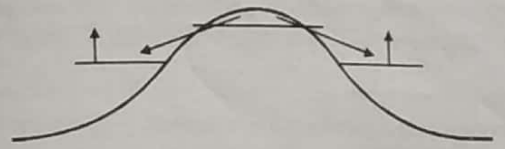

Fig. 4.5.1 (c) : Load Shifting

- **Load Shifting** - Shifting the load to non peak hours

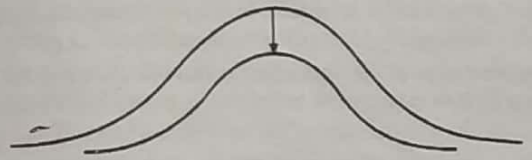

Fig. 4.5.1 (d) : Strategic Conservation

- **Strategic Conservation** - The reduction of utility load, more or less equally, during all or most hours of the day.

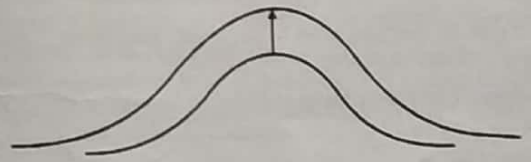

Fig. 4.5.1 (e) : Strategic Load Growth

- **Strategic Load Growth** - The increase of utility loads, more or less equally, during all or most hours of the day.

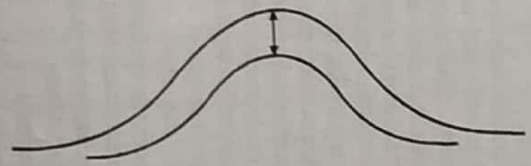

Fig. 4.5.1 (f) : Flexible Reliability

- **Flexible Reliability** - Agreements in which utility can alter customer energy consumption on an as-needed basis.

- The most popular strategies amongst these are Load clipping or Load shifting strategies and simply achieved by increasing energy rates for usage in peak duration.

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- The utilities, i.e., the State Electricity Boards (SEBs), effectively uses the tool of demand side management (DSM) to encourage the electricity consumers for consumption of electricity during off- peak hours by using one or many of the below mentioned measures:
  - Time of use tariffs
  - Penalties on exceeding allowed maximum demand
  - Night tariff concessions etc.
  - Power Factor Charges
- Load management serves as an effective mans for improvement of electricity usage for the utility as well as the consumers.
- Load management allows utilities to reduce demand for electricity during peak usage times, which can, in turn, reduce costs by eliminating the need for peaking power plants.
- Demand charges contributes to the significant amount of electrical bill hence control of the maximum demand by load management techniques is crucial from consumer point of view as well.

4.5.1 Strategic Approach for Maximum Demand Control :

(a) Load Curve

- Load demand of the consumer plotted against time of the day is termed as the "Load Curve"
- Depending on the intervals, it can be an 'hourly load curve', 'daily load curve', 'Monthly load curve', 'Yearly load curve'.
- A typical hourly load curve for an engineering industry is shown in Fig. 4.5.2.

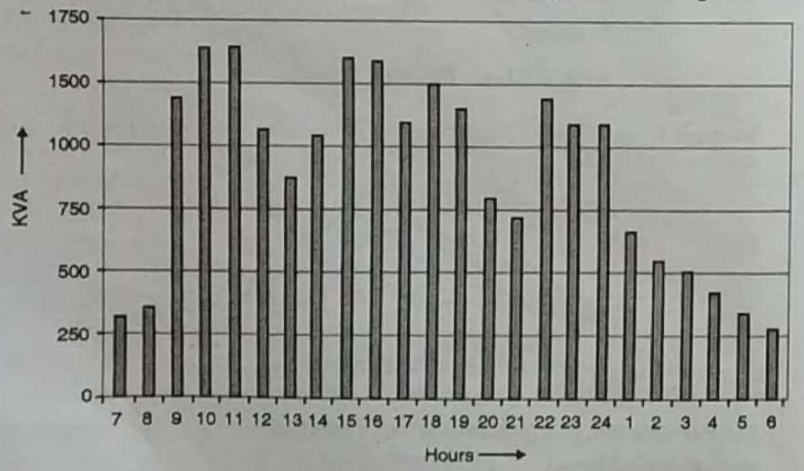

Fig. 4.5.2 : Maximum demand (Daily load curve, Hourly kVA)

- These types of curves are useful in predicting patterns of drawl, peaks and valleys and energy use trend in a section or in an industry or in a distribution network as the case may be.

(b) Rescheduling of Loads

- It is possible to reduce the burden on the utility by minimizing the simultaneous demands in order to minimize maximum demand by the time shifting of large electrical loads and operations.
- As a movement towards achieving this, it is very important to prepare a flow chart of operations and processes in the plant.
- By integral approach and rigorous analysis of these charts, the rescheduling alternatives for shifting the time of operations and running equipments can be found out such that it will spread the load uniform over the day and reduce the maximum demand.

(c) Shedding of Non-Essential Loads

- Shedding off the less important loads is another option to minimise the maximum demand when it reaches the predefined set limit.
- A direct monitoring system can be designed which will shed the non-essential loads on reaching the preset limit.
- Normally two types of system exist in this, manual and automatic.
- In a simple system, the loads need to be manually when there is an alarm on reaching the limit.
- Automatic systems are sophisticated ones that has various options of control which allows the operators to perform several sophisticated operations such as,
  - to predict the demand accurately.
  - to display graphically, the present load conditions, available load conditions and the demand limits.
  - Annunciation systems to provide visual as well as audio alert signals.
  - Shedding of load automatically, in a predetermined sequence which is decided by the operator
  - Automatically restore the load in a predetermined sequence which is decided by the operator
  - To monitor and record the various parameters of the system.

(d) Operation of Captive Generation and Diesel Generation Sets

- Captive power generation or the use of Generating sets to supply during the peak hours helps to reduce the load demand for that particular duration to a considerable extent.
- It helps to minimize the demand charges as well.
- For e.g. when Diesel Generation sets are available to use in the system, it is recommended to connect them in the system when demand reaches the peak value.

(e) Reactive Power Compensation

- An optimum power factor also positively effects in reduction of the maximum demand.
- As far as the plant level is concerned, the use of capacitor bank is an alternative that maintains the power factor at an optimum level.
- Latest capacitor banks come equipped with the microprocessor based control. These systems automatically switch on and off the capacitor banks according to the desired power factor and contribute to the maximum demand control.

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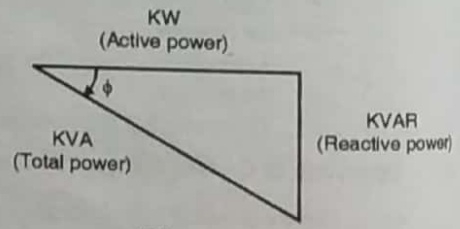
4.6 Power Factor Improvement and its Benefits

- Normally we consider the whole circuit comprising of resistance, inductance and capacitance.
- The cosine of the phase difference between the source voltage and current is termed as an electrical power factor
- There is always a fraction of power is used to do the useful work, power factor represents this factor in an electrical systems.
- In all industries major loads are resistive and inductive.

Resistive loads

- E.g. Incandescent lighting and resistance heating.
- The linear relation exists between the Voltage (V), Current (I), Resistance (R) in case of purely resistive loads.
  - $V = I \times R$
  - Power (kW) = $V \times I$
- Inductive type load:-
  - A.C. Motors, induction furnaces, transformers and ballast-type lighting are some of the examples of inductive load.
  - Inductive loads require two kinds of power :

    a) Active Power b) Reactive Power
- Active power is the require power required to perform the work and measured in kW (Kilo Watts).
- Reactive power is the power require to create and maintain electro-magnetic fields measured in kVAr (Kilo Volt-Amperes Reactive).
- The vector addition of active power and reactive power gives the total used power. It is called as Apparent Power.
- The power generated by the SEBs is Apparent Power which is used by consumer. Its unit is kVA (Kilo Volts-Amperes)
- The kVA reflects the actual electrical load on distribution system. (Refer Fig. 4.6.1).



$$PF = \frac{KW}{KVA} = \cos\phi$$

Fig. 4.6.1 : kW, kVAr and kVA Vector

- In a pure inductive circuit, the active power and the reactive power are 90° apart vectorically which implies the lagging of reactive power behind the active power. (Refer Fig. 4.6.1)
- The power factor is the ratio of the active power to the reactive power. It is always less than or equal to one.
- Unity power factor of all loads enable the maximum power transfer with the same distribution system capacity in ideal case.
- As most of the loads are inductive in nature that works with the poor power factor ranging between 0.2 to 0.9, the capacity of the electrical distribution network is stressed.

4.6.1 Need for Power Factor Improvement

- The term power factor comes into picture in AC circuits only.
- Mathematically, the power factor is Cosine of the phase difference between voltage and current.

$$\cos\Phi = \frac{\text{Active power}}{\text{Apparent power}} \text{ (Refer Fig.4.6.1)}$$

$$\text{Real Power, } P = V*I*\cos\Phi$$

- Electrical current I varies inversely with the Cos Φ to transfer the given amount of power at a particular voltage.
- It means if there is an increase in power factor, current will be lowered.
- Hence, lower power factor means higher the current through the conductor, higher current implies increase in copper losses.
- Also, increased current due to poor power factor causes large voltage drops in the various components of electrical system such as alternator, electrical transformer and transmission and distribution lines.

  We know,
- $kVA = \frac{kW}{\cos\varphi}$ (Refer Figure 4.6.1)
- Therefore, having higher power factor also offers an advantage of reduced kVA rating.
- The size and cost of machine is also reduced with the reduced kVA rating.
- So, maintaining the electrical power factor close to unity is very significant.

4.6.2 Improving Power factor

- Power factor improvement is nothing but the arrangement done to reduce the phase difference between voltage and current.
- As we know, most of the loads are of inductive nature, it demands some reactive power to function.
- The solution to improve the power factor is to install power factor correction capacitors or bank of capacitors in parallel to the load.
- Externally connected Capacitors act as a source of reactive power and supply the required reactive power to complete the kW of work.
- This leads to the increase in total power generated by utility by reducing the amount of reactive power generated by them.
- Basically, they reduce the phase difference between the voltage and current.

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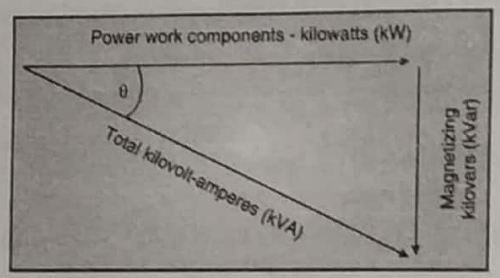

Fig. 4.6.2 : Before Power Factor Correction

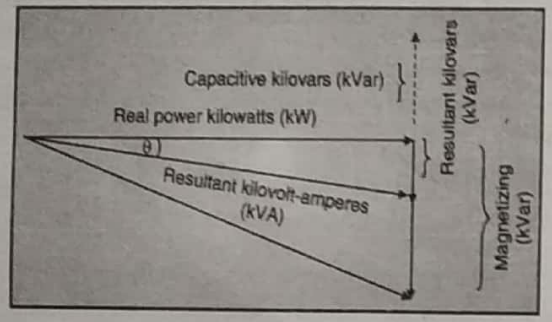

Fig. 4.6.3 : After Power Factor Correction

4.6.3 Benefits of Power Factor Correction

The PF can be thought of as a measure of electrical efficiency in a power system. Numerous benefits can be derived by providing power factor correction to a facility.

(i) Reduced Utility Bills

- A power factor is a major factor that directly or indirectly impacts utility electricity bill especially for industrial consumers.
- Consumer is penalised for the operation with low power factor. Power factor improvement effects in the reduction of these penalties.
- Power factor improvement reduces kVA (maximum demand) hence reduction in amount MD charges in electricity bill.

(ii) Electrical System Capacity

- Power factor improvement capacitors reduce the overall current required from the power supply to produce magentising power for induction motors and transformers.
- This reduce load not only on transformers but also on feeder circuits leading to increase in system capacity.

(iii) Improved Voltage Levels

- Automatic power factor correction capacitor panels dynamically compensate for the changing reactive power needs that maintains the required voltage levels and does not let to cripple the production line
- Better Voltage at motor terminals :
- Voltage at motor terminals are kept constant that improves the overall efficiency of the motors.
- Reduced Line Losses :
- Better power factor means reduced line current which results in reduced I^2R losses in line.
- Reduction in these losses reduces kWhr required by the industry.

4.7 Selection of Capacitors

- Selection of proper size of capacitors is very important as it decides the amount of kVAr to be supplied.
- Here we will discuss two ways of selecting a size of capacitors. One is direct relation of capacitor sizing and other is Table of capacitor sizing.

4.7.1 Direct Relation

$$\text{kVAr Rating} = \text{kW} [\text{Tan } \phi_1 - \text{Tan } \phi_2]$$

Where,

kVAr rating - Size of the capacitor needed
kW - Average power drawn
Tan ϕ_1 - Trigonometric ratio for the present power factor
Tan ϕ_2 - Trigonometric ratio for the desired PF.
ϕ_1 = Existing ($\text{Cos}^{-1} PF_1$) and
ϕ_2 = Desired ($\text{Cos}^{-1} PF_2$)

4.7.2 Capacitor Sizing using Multiplier Table

- Figures shown in the following table are the multiplication factors that are multiplied with the input power (kW). Result of this multiplication is the kVAr of capacitance required.
- The derived capacitance is the capacitance needed to improve present power factor to a new desired power factor.

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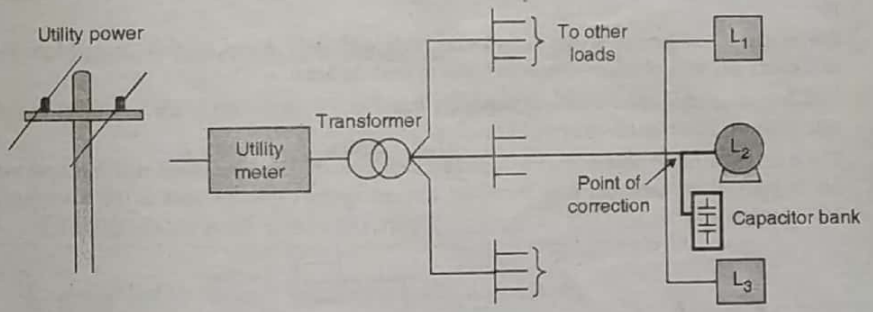
Original Power Factor	Desired Power Factor																			
	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.0
0.50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.589	1.732
0.51	0.937	0.962	0.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1.544	1.687
0.52	0.893	0.919	0.945	0.971	0.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	0.850	0.876	0.902	0.928	0.954	0.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.457	1.600
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1.416	1.559
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.093	1.124	1.156	1.190	1.227	1.268	1.316	1.376	1.519
0.56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.054	1.085	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.619	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.006	1.040	1.077	1.118	1.166	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.938	0.970	1.004	1.041	1.082	1.130	1.190	1.333
0.61	0.549	0.575	0.601	0.627	0.653	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.646	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.807	0.838	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.474	0.503	0.529	0.555	0.581	0.608	0.634	0.661	0.689	0.717	0.745	0.775	0.806	0.838	0.872	0.909	0.950	0.998	1.068	1.201
0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.966	1.026	1.169
0.66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.626	0.654	0.682	0.712	0.743	0.775	0.809	0.846	0.887	0.935	0.995	1.138
0.67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.965	1.108
0.68	0.328	0.354	0.380	0.406	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.786	0.827	0.875	0.935	1.078
0.69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.906	1.049
0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.371	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.535	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	0.936
0.74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.578	0.626	0.685	0.829
0.78	0.052	0.078	0.104	0.130	0.156	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
0.80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.265	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.609	0.750
0.81		0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82			0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.555	0.698
0.83				0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.529	0.672
0.84					0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85						0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86							0.000	0.026	0.053	0.081	0.109	0.137	0.167	0.198	0.230	0.264	0.301	0.342	0.390	0.450	0.593
0.87								0.000	0.027	0.055	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88									0.000	0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89										0.000	0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512
0.90											0.000	0.028	0.058	0.089	0.121	0.155	0.192	0.233	0.281	0.341	0.484
0.91												0.000	0.030	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.92													0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426
0.93														0.000	0.032	0.066	0.103	0.144	0.192	0.252	0.395
0.94															0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95																0.000	0.037	0.079	0.126	0.186	0.329
0.96																	0.000	0.041	0.089	0.149	0.292
0.97																		0.000	0.048	0.108	0.251
0.98																			0.000	0.060	0.203
0.99																				0.000	0.143
																					0.000

4.8 Location of Capacitors

- Location of the capacitor is very basic thing of correction.
- The primary purpose of capacitors is to reduce the maximum demand. Additional benefits are derived by capacitor location.
- Any electrical installation may have several power factors. Every electrical installation has locations where current changes (i.e. every branch) may have different power factor.
- Various locations of capacitors for power factor correction are,
  - At the Load
  - At the Load Control Center
  - At the Substation Transformer
  - At the utility Meter

4.8.1 At the Load

- This location for installing the power factor correction capacitors is assumed to be the best location among all. However, it is important to do this during initial construction otherwise it proves very expensive.
- In this system, when the motor is switched off, the capacitor with that motor automatically comes out of the circuit as it is not needed. This is an additional benefit.



Delivery path of VARs to Load

Part of installation relieved of delivering VARs due to PF capacitors.

Fig. 4.8.1 : Capacitors connected at the Load.

4.8.2 At the Load Control Center

- In the cases where we have several Loads fed from a Load Control Center (LCC), a convenient PF correction location is at this one point.
- In this arrangement, a large group of capacitors is installed at the center from which all loads are powered. The location is termed as Load Control Center (LCC).
- The undesirable aspect of this arrangement is that a bank of capacitors supplies excess reactive power even if some of the loads are taken off or switched off.

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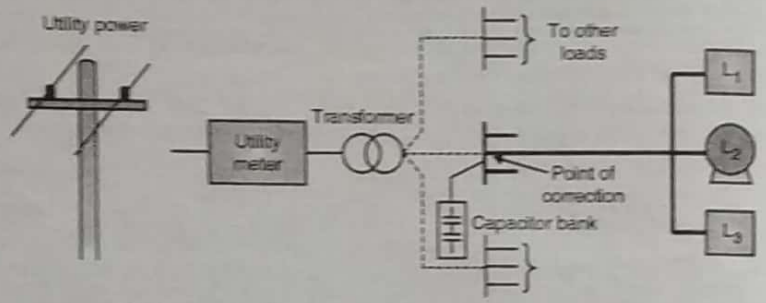
- Switching segments of capacitance with an arrangements of putting them in or out according to the change in load is desirable.
- Automatic Power Factor Correction Panel is one such option.



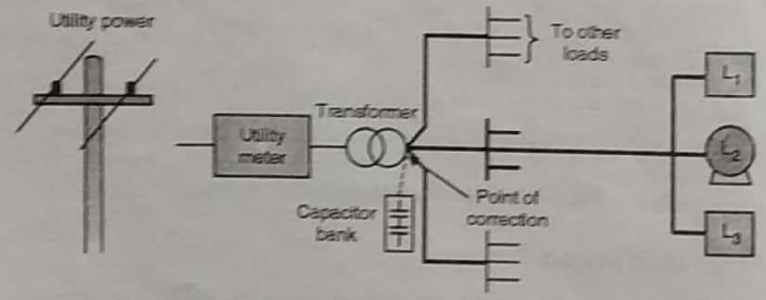
Delivery path of VARs to Load

Part of installation relieved of delivering VARs due to PF capacitors.

Fig. 4.8.2 : Capacitors connected at the load control centre

4.8.3 At the Substation Transformer

- Reduction in amps of substation transformer is important if we want to reduce the kVA load on it.
- Power factor correction at the transformer side definitely helps in this case. Moreover, it minimizes the need of other sources required to feed the load.
- In this arrangement, the location of capacitor bank for PF correction is the key point i.e correct side of the transformer (Secondary / Primary).
- The point to be noted here is that the capacitor bank benefits the installation which is upstream of the tie point of the capacitor bank therefore, connecting the capacitor bank at the secondary side is recommended.



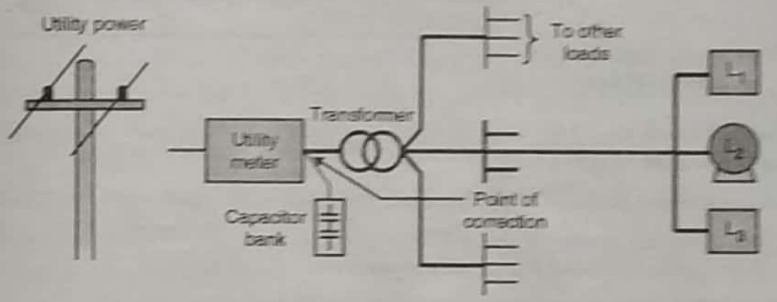
Delivery path of VARs to Load

Part of installation relieved of delivering VARs due to PF capacitors.

Fig. 4.8.3 : Capacitors connected at the substation transformer

4.8.4 At the Utility Meter

- When it comes to reducing the large reactive demand charges without connecting the capacitor inside the plant, connecting it at the utility meter side is another alternative.
- This means installing the power factor correction capacitor bank at the service entrance.
- Electrically, this arrangement is more beneficial for the utility lines.
- However, this eliminates the need of supplying the VARs to particular consumer and leads to increased available current capacity of those lines which they can sell to other more number of consumers.
- Ultimately it results in the decreased or no "Reactive Penalty".



Delivery path of VARs to Load

Part of installation relieved of delivering VARs due to PF capacitors.

Fig. 4.8.4 : Capacitors connected at the utility meter

4.9 Distribution and Transformer Losses

- In any electrical system, two kinds of losses are inevitable viz.
  - Constant No Load Loss
  - Variable Load Loss
- Assessment of these losses over a longer reference duration is very essential in order to estimate total energy losses.
- Vast experience and knowledge of the factors having influence on the operating efficiencies of various components is crucial to complete the challenging task of identification and calculation of sum of individual contribution of various components of the system towards losses.
- Various Technical Losses in Distribution and Transformer are as mentioned in following figure and subsequent section.

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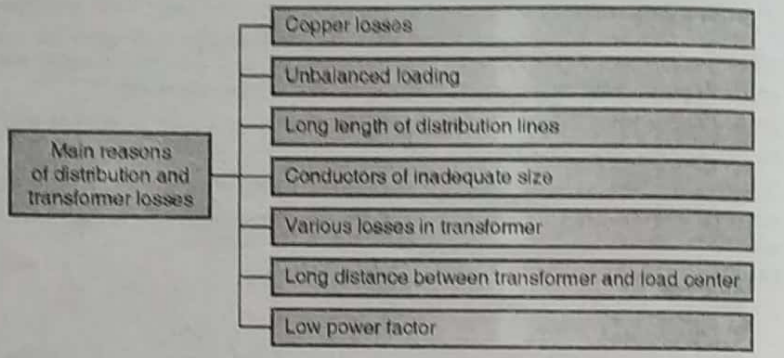
Main reasons of distribution and transformer losses
Copper losses
Unbalanced loading
Long length of distribution lines
Conductors of inadequate size
Various losses in transformer
Long distance between transformer and load center
Low power factor

4.9.1 Copper Losses

- One of the main sources for losses in distribution system is Copper losses in the lines connecting substation to the consumer loads.
- Copper loss is a major aspect in which all the real power of the distribution system is lost.
- Copper losses are function of square of line current so it's well obvious that losses will be higher at higher power levels than that at lower power levels.
- These losses claims most of the power losses in distribution system, given by,

$$P_{loss} = I^2R \qquad \ldots(4.9.1)$$

- So any reason which causes change in either line current or line resistance will directly affect the power loss in line.
- Factors that regulate magnitude of the line current are,
  - Real and reactive power loading of the line, as the power through line increases current increases and hence losses.
  - Operating voltage of the line. Higher the operating voltage lower the line current (hence losses) and vice versa.

4.9.2 Unbalanced Loading

- Unbalanced loading is another factor that can cause higher line losses.
- If any of the phases is more heavily loaded as compared to other ones, losses would definitely be higher than it would have been if lines were loaded evenly.
- Reason behind this lies in Equation 5.7.1.
- For example if one of the line is carrying the current double to that of other two lines. Considering all other factors constant. Copper loss under this loading condition will be 12.5% more than losses which would have occurred under balanced loading.
- Balancing line currents in distribution system may lead to considerable loss savings.
- It can be done by adding some switches to shift the load from loaded feeder to less loaded one.

4.9.3 Long Length of Distribution Lines

- Long Distribution Lines means results in high line resistance and thus high I^2R losses.
- Though the currents cause line losses significantly, the resistance is also a factor that has a considerable effect on the power loss.
- The factors on which line resistance depends includes
  - Length of line
  - Effective cross sectional area
  - Resistivity of the material

$$R = \rho \frac{L}{A} \qquad \ldots(4.9.2)$$

- Resistance varies directly with length and resistivity and inversely with cross sectional area.
- Therefore, for the same magnitude of line current longer line will have more losses than shorter.

4.9.4 Conductors of Inadequate Size

From Equation (4.9.2) it can be observed that the conductor of smaller size will cause more losses than conductor of larger size.

4.9.5 Losses in Transformer

Transformer employs copper conductor to produce magnetic field in steel core so transformer losses includes both core losses and copper losses.

(a) Copper Losses
(b) Core Losses
(c) Harmonic Losses

(a) Copper Losses

- Copper losses is nothing but dissipated heat by the current in primary as well as secondary winding which can be found out by current square relation with resistance as discussed earlier which can be observed in Equation 2.
- Any factor affecting current and winding resistance obviously affects copper loss in transformer.
- Increase in real or reactive loading causes more flow of current hence more copper losses.
- Resistance of winding depends upon length and size of winding conductor. This has an important contribution in amount of copper loss in transformer.
- Change in temperature of the winding causes change in resistivity of the winding conductor hence overall resistance hence copper losses of the transformer.

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(b) Core Losses

- Core losses accounts much more than copper losses in transformer in magnitude.
- Power as well as distribution transformer are permanently stay connected in the system so no load losses are essential to be considered. Core losses are independent of loading.
- Core losses are function of :
  - Type of lamination
  - Material of core
  - Insulation
  - Voltage
  - Frequency
- Core losses are made up of Eddy current loss and Hysteresis loss.
- Eddy current losses are a result of magnetically induced current in the core and given by,

$$P_e = K_e * f^2 * B_m^2 \quad \text{...(4.9.3)}$$

- Hysteresis loss causes due to reversals of magnetic cycles (owe to imperfect core material) and given by,

$$P_h = K_h * f * B_m \quad \text{...(4.9.4)}$$

Where,

f - Frequency

B_m - Flux density of the core material

K_e, K_h - Eddy current and Hysteresis loss constant.

(c) Harmonic Losses

- Presence of harmonics in the system can increase losses in transformer.
- High frequency voltage may lead to large core losses in the transformer however it hardly affects copper loss.
- Greater losses due to occurrence of skin effect in larger conductor with high frequency harmonics.

4.9.6 Distance of Distribution Transformer from Load Centers

- In secondary distribution system, generally transformers are located far away from the consumers instead of any suitable central location.
- Though secondary voltage is maintained properly, farthest consumer receives very low voltages at his end.
- Decreased voltage at consumers end results in withdrawal of higher currents hence higher line losses.

4.9.7 Low Power Factor

- Inductive loads for e.g. motors in agricultural applications having lagging power factor without capacitors pull the power factor to an undesirable limit.
- A low power factor results in high distribution loss.
- If power factor is low, current drawn is high for the given load.
- Hence lower the power factor higher the current and higher the losses associated with square of the current.

4.10 Optimization of Distribution and Transformer Losses

- In order to optimize the above mentioned distribution and transformer losses various options are available, major of them as follows.
- Location of transformer and substation should be chosen such that Distance between distribution transformer and consumer will keep voltage drop as low as possible.
- Re-rerouting and re-conductoring of feeders with high line losses and voltage drop such that it will bring losses within permissible limits.
- Losses owing to the low power factor can be minimised by employing capacitors at the load end.
- System Voltage Optimization and Phase Current Balancing.
- Efficiency of the transformer is increased by minimising the incurred losses. It can be improved by paying attention towards,
  - Design factors that can bring losses to a lower level
  - Improvement of transformer core by the use of latest advanced material for e.g. amorphous iron.
- Use of All Aluminium Alloy Conductors (AAAC) that has lesser resistance in place of conventional Aluminium Cored Steel Reinforced (ACSR) conductors

Review Questions

Q. 1 What are the various analysis techniques used in the energy optimization. Explain any one of them.

Q. 2 Define Energy Monitoring and Targeting. What are the key elements?

Q. 3 Write a note on relation between energy consumption and production in the context of Energy monitoring and targeting.

Q. 4 Elaborate the role of Data and Information analysis to understand energy management potential.

Q. 5 Write a detailed note on CUSUM technique.

Q. 6 Explain how energy analysis by CUSUM technique helps for the energy optimization.

Q. 7 What is tariff ? State the various components of tariff.

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Q. 8 What is the significance of maximum demand? Write a note on strategies of maxim demand control.

Q. 9 Write a detailed note on electrical load management.

Q. 10 Why power factor correction is necessary? State various benefits of the same.

Q. 11 Explain the effect of various capacitor locations on power factor correction.

Q. 12 What are the various ways of calculations of capacitor size for the PF correction?

Q. 13 State and explain various distribution and transformer losses.

Q. 14 State various measures to minimize the distribution and transformer losses.

4.11 University Questions and Answers

May 2016

Q. 5(a) Explain step by step approach in load management. (10 Mark
(Ans. : Refer Section 4.5)

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UNIT V

CHAPTER 5

Energy Audit, Electrical Energy Performance Assessment

Syllabus :

Energy Audit :

Introduction to Energy Conservation Act 2001 and ECBC 2007. Energy Audit: Definition,-need, Types of energy audit, Energy Management (audit) approach-understanding energy costs, Bench marking, Maximizing system efficiencies, optimizing input energy requirement, fuel and energy substitution. Energy Audit instruments.

Electrical Energy Performance Assessment :

Motors And Variable Speed Drives, Lighting Systems. Basics of HVAC system assessment for electrical energy usage.

Objectives

After studying the chapter you will be able to :

- Understand energy conservation act 2001
- Understand energy conservation building codes
- Know the need of energy audit
- Understand energy audit methodology.
- Know the benchmarking
- Understand instruments and equipments used in energy audit.
- Understand variable frequency drive.
- Find out the load efficacies
- Know the performance assessment of HVAC system

Part I : Energy Audit

5.1 Introduction

- The scenario of energy shortage is compelling the adoption of energy conservation measure, which essentially means using less energy for the same level of activity.

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- Energy audit has been gaining continuous attention due to its vital role in the business practice of the successful organizations of reducing energy cost and management of energy expenses.
- Energy audit is sometimes called as an "energy assessment" or "energy study"
- The motive of energy audit is to identify opportunities of energy efficiency by finding out answers of where, why and how energy is being used in the facility.
- Energy auditing services are offered by
  - Energy services companies (ESCOs)
  - Energy consultants
  - Engineering firms.
- Though energy auditor conducts the audit, facility owner and staff are also the key participants throughout as they ensure the accurate data collection and appropriateness of energy efficiency recommendation.
- Typical audit procedure starts with taking a review of historic and current utility data followed by benchmarking of facility's energy consumption against other similar facility. Onsite inspection of the physical building is done on the basis of this.
- Outcomes of energy audit are comprehensive list of Energy efficiency measures (EEMs) with related energy saving potential derived from building and facility performance.
- Energy audit also includes assessment of cost effectiveness of these recommendations.
- Energy audit in industries is often done keeping an eye over key energy guzzlers in the overall system e.g. motors, lighting system, HVAC, etc.
- Organization gains notable experience of how to manage energy consumption and cost while conducting an Energy audit.
- Auditing process makes user or employee in case of industry aware in many ways.
  - Employee considers energy as a manageable expense.
  - Start critical analysis of ways of facility's energy use.
  - Becomes alert about how their day-to-day actions affect plant energy consumption.

5.2 Energy Conservation Act - 2001

- Energy conservation act 2001 frames some legal aspects so as to promote energy conservation.
- Policies and provisions under this act keep in content
  - Benefits of high energy saving
  - Reduction the demand supply gas
  - Reduction of harmful emissions to environments via energy saving.
- Establishment of Bureau of Energy Efficiency (BEE) in association with Ministry of power regulated Energy Management centre is under the provision of this act.

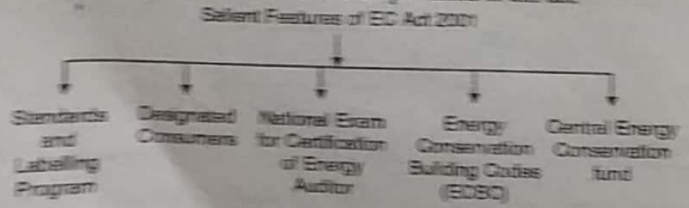
Salient Features of EC Act 2001
Standards and Labelling Program
Designated Consumers
National Exam for Certification of Energy Auditor
Energy Conservation Building Codes (ECBC)
Central Energy Conservation fund

Fig. 5.2.1 : Salient features of energy conservation Act 2001

Salient features of Energy Conservation Act 2001 are

- Standards and labeling (S and L) program specify the consumptions and performance standards for appliances in order to prevent energy inefficiency.
- S and L program mandates for every notified equipment or appliance, a label showing performance so that consumer can have information of his choice.
- This brings in the constraints of standards and efficiency on production and transactions of substandard equipment.
- Energy intensive premises such as industries, commercial buildings and establishments such as railways, port, trust, etc. are notified as designated consumer.
- Designated consumers have to adhere to the energy consumption standards imposed under the act and should get their energy audit done from certified energy audits.
- In this regard, an activity of development of professional, qualified expert energy managers and auditors is done by BEE.
- BEE conducts a national level exam and these persons are certified or accredited. Moreover training modules are also designed to increase total expertise in energy efficiency and conservation.
- Energy Conservation Building Codes (ECBC) suitable to respective local climate or other driving factors have been developed and notified to designated consumers that are compulsory to comply with.
- ECBCs are made obligatory for the buildings which serve commercial purpose having connected load of atleast 500 kW or 600 kVA contract demands.
- In this context, designated consumer should get energy audit conducted in such manner and at prescribed time intervals by as BEE certified energy auditor.
- Central Energy Conservation Fund set up at the centre should be used such that it will give impetus to R and D and encourage widespread use of energy efficient equipment's and appliances.
- It also includes use of funds to create facility of testing to improve consumer awareness.
- Expected role of Central Government according the act is,
  - To assist BEE financially by setting up energy
  - Conservation funds
  - Provide various subsidies on equipments promoting energy efficiency and coordinate with state governments in all related legal issues.
- State government is presumed to
  - Modify the ECBC to adapt for regional and local climatic conditions.
  - Appoint state level bureaus to execute various provisions made in energy conservation act properly.
  - Establish a fund in order to promote state energy conservation activities.
- Monetary penalties would be imposed in the case of offending the provisions of this act.
- BEE - Bureau of energy has been established under the energy conservation Act - 2001 with the primary objective of reducing energy intensity in the Indian Economy.
- BEE is managed by a commission of 26 members. This commission is lead by Union Ministry of Power and CEOs of technical agencies under ministries.
- Representative members of manufacturers, consumers, five power regions representing states are the various members.

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5.3 Energy Conservation Building Codes

- The International Institute for Energy Conservation (IIEC) developed a set of energy performance standards in association with the United States Agency for International Development (USAID). This was under the activity of supporting the Bureau of Energy Efficiency (BEE) action plan under the Energy Conservation and Commercialization (ECO) project.
- It is obligatory for all commercial buildings that are to be constructed in India to follow the set of energy performance standards specified in this document named "Energy Conservation Building Code (ECBC)". It is launched on 28 June 2007.
- The motive behind developing ECBC is to provide a basis for the design and construction of the building with the major consideration of energy efficiency.
- The code is compulsory for all commercial buildings or complexes having
  - a connected load of 500 kW or greater
  - a contract demand of 600 KVA or greater.
  - a conditioned floor area of 1,000 m^2 (10,000 ft^2) or greater.
- ECBC recommends efficient design or retrofit of buildings such that it does not alter the building function, comfort, health, or the productivity of the occupants.
- It also appropriately considers economic viability and minimizes life cycle costs (construction + energy costs)
- According to the plan the codes are compulsory for commercial buildings once enforced.
- ECBC has been developed after the vast data collection and analysis regarding
  - Building types,
  - Building materials,
  - Equipments like Air conditioning, lighting etc. that are common in India.
- Climatic condition is one of the very important factor that ECBC accounts. There are 5 distinct climatic zones in India and ECBC takes this zone into consideration while designing the building envelope.
- The development of ECBC had participation of all major stakeholders:
  - Government
  - NGOs
  - Industry
  - Financing institutions.
- As the current ECBC is first activity of its kind in India therefore due consideration is given to the simplicity in implementation while designing the code.

5.3.1 The Provisions of ECBC

- The provision in Energy Conservation Building Codes mainly addresses the following areas
  - **Building envelopes;** It excludes unconditioned storage spaces or warehouses.
  - **Mechanical systems and equipment;** It includes heating, ventilating, and air conditioning.
  - Service hot water heating
  - Interior and exterior lighting

  - Electrical power and motors
  - Water heating and pumping systems (including requirements for solar hot-water systems)
- The ECBC provisions are not applicable for :
  - Buildings that do not require electricity or fossil fuel to fulfill their energy needs.
  - Facilities and parts of building systems that uses energy mainly for the purpose of manufacturing process
  - Multi-family buildings of three or fewer stories above grade, and single-family buildings.

5.3.2 Approaches for Compliance

ECBC Provides three approaches for compliance:

1. **Component-based (Prescriptive) :**
   - Component-based or Prescriptive approach observes the acceptable completion of performance requirements of each subsystem and system.
   - Prescriptive Method lays some basic predetermined minimum levels of energy efficiency parameters which is mandatory to be followed at various components and systems of the subject building.
   - It requires little energy expertise.
   - It offers no flexibility.
2. **System-based (Trade-off)**

   Building Envelope Trade-Off Option
   - In this approach, actions are taken according to comply with the performance needs of each system and also balance is achieved between the desirable but incompatible features of the subsystems.
   - This is a systems-based approach, where the thermal performance of individual envelope components can be reduced if compensated by higher efficiency building components.
   - This approach brings a balance between high efficiency components and lower efficiency components. It improves the flexibility of the system.
3. **Whole building design analysis (Performance)**
   - Whole Building Performance (WBP) Method is an alternative method to comply with the Code.
   - This method is more complex than the Prescriptive Method, but offers considerable design flexibility.
   - Allows flexibility in meeting or exceeding **energy efficiency** requirements (as compared to a baseline building)

5.3.3 Implementation

The BEE has been undertaking some initiatives to encourage the implementation of ECBC. Some of the major steps of BEE towards this are;

- Capacity building of agencies that implement ECBC at state as well as municipal level.

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- Provide all types of technical support to Architects, Engineers, and Code Officials. The help includes;
  - Design Manuals
  - Software
  - Training related activities
  - Conduction of awareness programmes and activities for building owners and users.

  Appreciate the implementation by giving energy conservation awards.
- The energy consumption of the ECBC-compliant buildings has been observed to be 40 to 60% less when simulated. .

5.4 Energy Audit

5.4.1 Definition and Concept

- An organised approach that acquire understanding of existing energy consumption pattern of the facility, highlights the aspects that influence the energy usage and pinpoints cost effective saving opportunities is termed as Energy Audit.
- Energy Conservation Act, 2001 defines Energy Audit as "the verification, observation and investigation of energy use that also includes writing a technical report comprising suggestions for improving energy efficiency with economic analysis and an action plan to lower energy consumption".
- Simply an Energy Audit is a survey that is made by the client organisation and energy professionals with a joint effort.
- It is a top-down initiative and resources that building management allocate to energy audit largely influence its effectiveness.
- Energy Audit enables the client organisation to adopt a systematic approach while taking decisions related to energy management.
- Energy audit aims to bring stability between total energy inputs and its use. It identifies the energy distribution channels in a facility.
- Energy usage in the facility follows some discrete function. The usage is quantified according to its distinct function.
- Energy Audit proves to be an important tool that establish and pursue a comprehensive energy management programme.

5.4.1.1 Components of Energy Audit

- General components procedure of energy audit can be summarised in three steps,

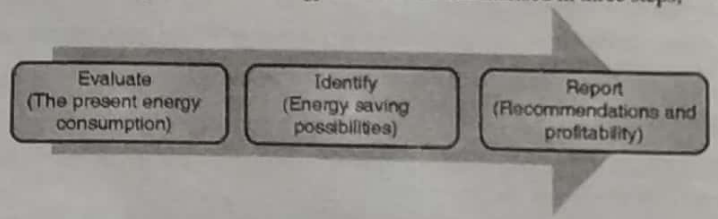

Fig. 5.4.1 : General procedure of energy audit

- These components are discussed in detail in subsequent sections.

5.4.1.2 Objectives of Energy Audit

- Find out the quality and pinpoint the cost of various energy input.
- Assess the present energy usage pattern in different cost centres of operations.
- Establish a relation between Energy Consumption and Production.
- Identify the areas having potential to be thermally and electrically economical.
- Pinpoint the energy wastages in key areas.
- Set energy saving target at each cost center.
- Implement Energy Efficiency Measures and understand savings.

5.4.2 Need of Energy Audit

- The major costs incurred in any type of industry owe to three aspects Energy, Labor and Materials. Energy includes both Thermal as well as Electrical.
- When it comes to manage the cost or to find out the area with potential of cost saving out of these aspects, energy always appears to be on top amongst them thus the any programme as an approach towards cost saving mainly involves energy management.
- Energy Audit helps to perceive all the information related to Energy use in the industry such as,
  - Process of Energy and Fuel use
  - Possible areas of unnecessary excess use of energy
  - Pinpoint where the scope for improvement exists.
- Crucial tasks related to production and utility encompasses the activities of,
  - The energy cost reduction
  - Preventive maintenance
  - Quality control programme
  - Energy audit aids to execute these tasks effectively giving it a positive direction.
- Energy Audit Programme helps to keep to keep the track of,
  - Disparity in Energy costs
  - Imbalance in availability and reliability of energy supply
  - Appropriateness of energy mix
  - Addition of new energy conservation installations and equipments etc.
- In essence, Energy audit is nothing but a conversion of energy conservation idea into practical action with the help of suitable technical solutions.
- These solutions are feasible with respect to economic and other organizational constraints and specified for a particular time frame.
- Major objective of the industrial energy audit is to find ways
  - To curtail the energy consumption per unit of product output
  - To reduce the operating costs.
- Energy audit offers a starting point towards deciding a procedure for better energy utilization throughout the organization.
- Energy Audit provides a "bench-mark" (Reference point) to compare with so that energy can be managed properly at the facility.

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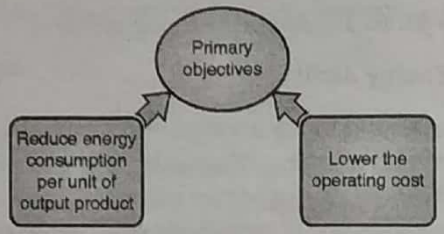

Fig. 5.4.2 : Primary Objectives of Energy Audit

5.4.3 Types of Energy Audit

Depending on the level of detail of the collected information, energy audit is categorized into two types

(i) Walk through Audit

(ii) Detailed Audit

5.4.3.1 Walk Through Audit

- It is alternatively called as the preliminary audit or screening audit or simple audit.
- Walk through is the simplest, quickest and least expensive way of identification and evaluation of energy saving opportunities.
- Generally there are two resources of data to perform walk through audit such as,
  - Operation and Maintenance staff collects the data.
  - Serving utility provides this information.
- Basic information of the energy systems in the premises is collected as well.
- Walk through audit procedure involves,
  - Review of energy bill of the premises
  - Other operating data.
  - Walk through of the premises to be familiar with the system whose audit is to be done so that inefficient areas can be identified.
- People have major influence on the energy usage hence this audit pays attention to habits and practices encouraging energy efficient use.
- Expenditures for this audit can be included in Operation and Maintenance cost.
- Only main issues are covered in walk through procedures.
- Walk through audit is a relatively quick exercise which gives, Areas for more detailed study/measurement.
  - Brief description of corrective measures.
  - Energy conservation measures (ECMs)
  - Energy Conservation Opportunities (ECOs)
  - Estimate of implementation cost
  - Main areas of operation cost saving
  - Simple payback Period.
- Though walk though audit is not sufficient for final implementation of measures, it provides the need of depth of Detailed Audit which is more elaborative as compared to Walk Through Audit.

5.4.3.2 Detailed Audit

- It is also known as General Audit or In-Site Energy Audit.
- Detailed energy audit is nothing but expansion of the simple audit discussed above.
- This method of audit also collects information of system operation, but in more detailed form as compared to Simple Audit.
- Energy conservation measures which were identified in Walk through audit are evaluated in all respect in Detailed Audit.
- This type of Energy Audit involves,
  - Collection and processing of data from in-site measurements
  - Full examination of the installed energy systems of the building/unit, which will permit to compose a thorough energy
  - A sound techno-economical evaluation of one or more energy-saving approaches, with medium to high investments on specific systems after a relevant study.
- Auditor collects utility bills of an year or two and analyses in order to find out,
  - Energy tariff structures for the system under study
  - Energy usage profile
- The energy consumption is disaggregated in different end-uses e.g
  - Heating
  - Cooling,
  - Lighting,
  - Different processes, etc.
- The different factors that affect the end-use are presented and analyzed e.g.
  - Production or services capacity,
  - Climatic conditions,
  - Raw material data, etc.
- Proper metering in the system may perform a major role in this type of audit.
- In addition to data provided by utility, specific energy consumption in the system is metered.
- Metering of data at certain intervals gives exact energy utilization profile of the system under study. This profile is analyzed for points of energy waste.
- System can have various energy consumption patterns viz. short term, long term. These are understood by having a detailed interview of the working staff of that particular system.
- This type of audit focuses all the most suitable energy conservation measures for the system.
- Another important aspect of the detailed audit is Financial Analysis.
- For each suggested measure Financial analysis is done on the basis of
  - Investment criteria defined by consumer
  - Estimate of implementation cost
  - Operating cost savings.
- Detailed energy audit may be divided into three phases namely
  - Pre Audit Phase
  - Audit Phase
  - Post Audit Phase

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- The type and extent of energy audit to be performed essentially depends on:
- Genre of industry
- Intensity of requirement .Scope and amount of expected cost reduction.

5.5 Energy Management (Audit) Approach

5.5.1 Energy Audit Methodology

- Energy audit methodology has to be flexible as infrastructure and processes vary industry to industry.
- A detailed methodology for conducting an energy audit on field is given and discussed below.
- An energy manager or auditor can use these steps to start and can make necessary changes according to the industrial requirement.

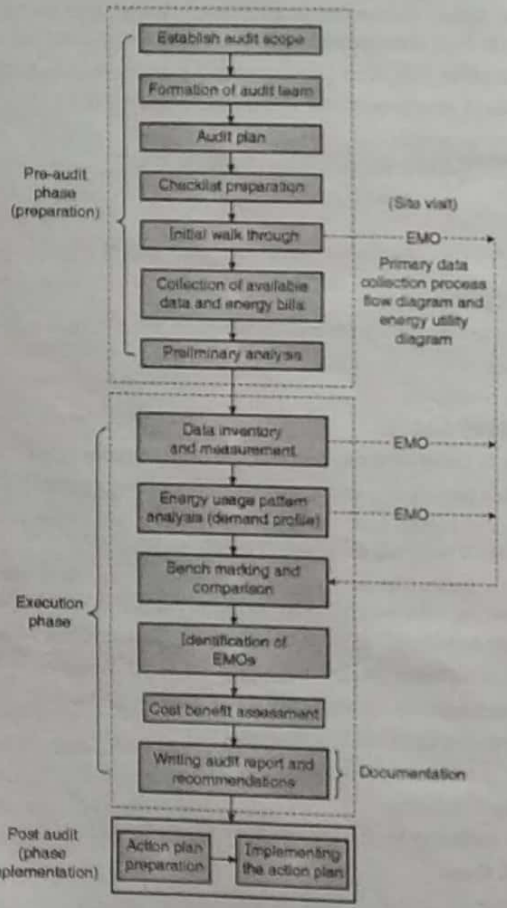

Fig. 5.5.1 : Energy audit procedure

Each of the above stages has several sub steps. All these can be summarized in three phases of Audit.

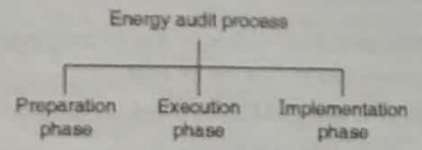

Fig. 5.5.2 : Phases of Energy Audit Process

5.5.1.1 Preparation and Planning Phase

Consideration of various criteria such as objectives, type, standards, staff involvement, site boundaries, time constraints and reporting requirements of the audit is very important before starting the actual procedure.

(a) Define Audit Scope

- Energy system to be audited is defined in audit scope. It needs to take into consideration the various available resources such as staff time, degree of details and budget in order to carry out the energy audit.
- Audit scope may be limited particularly to any process or equipments of the total plant.
- It should also define comprehensiveness as well as level of analysis for final recommendation.

(b) Form an Audit Team

- This is a task of company manager.
- It is a decision of manager, whether to conduct the audit by internal company staff or outside consultant. Energy auditor accredited by government agencies is highly recommended.

(c) Develop an Audit Plan

- An audit plan is a document that summarizes the strategy and process of audit.
- It is a crucial tool to keep the track of consistency, completeness and resource utilization in audit. An audit plan should provide the points shown in following figure.

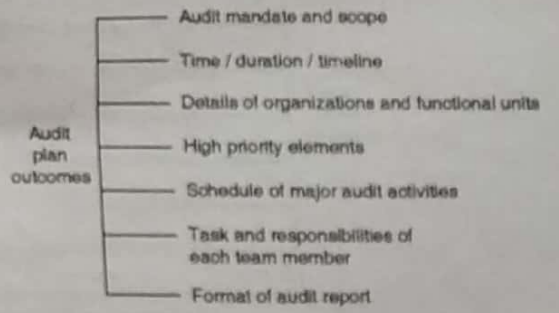
Audit plan outcomes
Audit mandate and scope
Time / duration / timeline
Details of organizations and functional units
High priority elements
Schedule of major audit activities
Task and responsibilities of each team member
Format of audit report

Fig. 5.5.3 : Outcomes of audit plan

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(d) Prepare an Audit Checklist

- An audit checklist provides a systematic way to carry out the audit. An audit checklist provides a systematic way to carry out the audit.
- Key constituents of an Energy Audit are shown in Fig. 5.5.4.

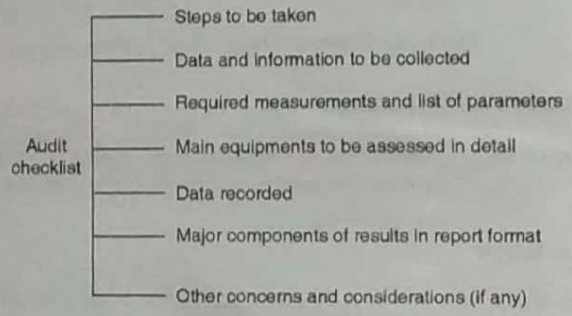
Audit checklist
Steps to be taken
Data and information to be collected
Required measurements and list of parameters
Main equipments to be assessed in detail
Data recorded
Major components of results in report format
Other concerns and considerations (if any)

Fig. 5.5.4 : Energy Audit checklist

(e) Visit the Site

- Energy audit team gives an initial walk through visit in premises to be audited to be familiar with plant/process activities.
- Existing level of the operation and the practices are observed in this walk through.

(f) Energy Bills and Available Data Collection

- It includes collection of data and information regarding existing as well as historical energy. Necessary primary data is shown in Fig. 5.5.5.

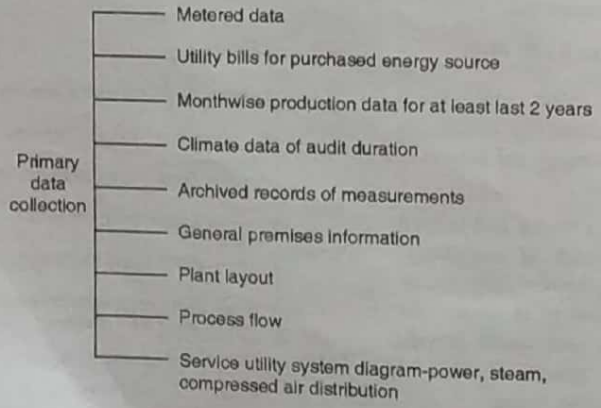
Primary data collection
Metered data
Utility bills for purchased energy source
Monthwise production data for at least last 2 years
Climate data of audit duration
Archived records of measurements
General premises information
Plant layout
Process flow
Service utility system diagram-power, steam, compressed air distribution

Fig. 5.5.5 : Primary data for audit

(g) Preliminary Analysis

- Preliminary analysis gives Energy auditor a better understanding of the system to be audited as it highlights,
  - Energy usage of company
  - Energy Losses
  - Operations
- The preliminary analysis provides sufficient information to make the necessary changes in the plan of energy audit if any.

(h) Energy Bill Analysis

- Analyzing energy bill properly is very important to understand facilities energy cost.
- Every bills includes
  - Electricity bill
  - Natural gas bill
  - Coal/fuel oil bills
- It needs to go through tariff structure. Various components of these bills in order to conduct correct analysis as it greatly influences saving calculations.
- **Electricity bill :** fixed charge, demand charge, per kwh charge
- **Natural gas bill :** Days, reading date, contract demand, overrun, customer change, gas supply charge.
- Basic study of previous energy bills gives insight of unit cost of purchased energy. This information is vital to evaluate cost saving at the end stage of audit.

5.5.1.2 Execution Phase

(a) Data Inventory and Measurements

- The energy auditor needs to understand the total energy load distribution among various systems in the plant. The load inventory systematically collects the data of,
  - Locations of energy use
  - Amount of energy use
  - Rate of energy use
  - How all consumptions are aggregated as a whole.

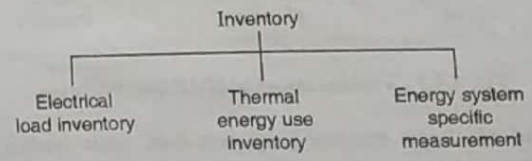

Fig. 5.5.6 : Various data inventory

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- Most common data measured in energy auditing are,
  - Fuel flows (Liquid / Gas)
  - Electrical parameters (Voltage/Current/Various Powers / Power Factor)
  - Temperatures
  - Pressures (in Pipes/Furnaces/Vessel)
  - Exhaust gas emissions (CO_2, CO,O_2)
  - Relative humidity
  - Luminance levels

(b) Demand Profile Analysis

- The demand profile is nothing but energy consumption or usage pattern of the facility.
- Proper interpretation of the demand profile gives the key information that includes,
  - Continuously operating loads (shut down)
  - Loads which unnecessarily increases peak demand
  - Abnormally operating loads (maintenance)
  - Contribution of various loads in the demand profile.
  - Load shifting opportunity.

(c) Bench Marking and Comparative Analysis

- In this analysis, energy consumption level is compared with similar industries/sites.
- It can determine the level of energy consumption which can be achieved by adopting best operating practice and industrial benchmarks.
- Energy consumption of this year is compared with that of the last year.
- Energy performance of one site is compared with that of the other site.

(Refer section 5.5.3 for the detailed discussion on benchmarking.)

(d) Identification of Energy Management Opportunities

- It can be observed from audit process flow chart that identification of EMOs is possible at several stages.

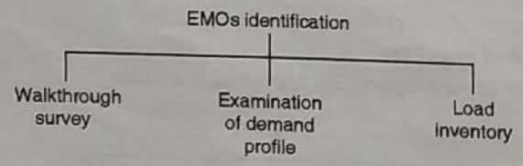

Fig. 5.5.7 : Various stages of EMO identification

- One should not forget the key point here that, while finding out EMOs, original requirement must be met whilst reducing energy usage level.
- Approach to find out EMOs may includes, 3 steps.

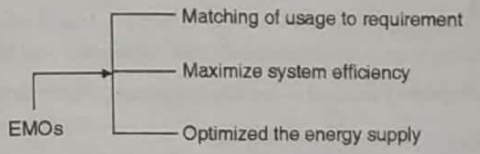

Fig. 5.5.8 : Steps in approach towards EMO

Stages	EMOs
Walk Through Survey	• Needs of Repair • Operational changes
Examination of Demand Profile	• Load shifting opportunities • ON Loads during Shutdown
Load Inventory	Distribution of energy consumption in various plant stages.

(e) Cost-benefit Assessment

- Comprehensive assessments of costs and benefits associated with energy saving measures Or an opportunity goes beyond the involved energy costs.
- A detailed cost benefit analysis provides a base for energy saving option by interpreting.
  - Technical work ability
  - Economic viability
  - Selection of the most optimistic projects
  - Prioritization of measures as Low, Medium, High
- More specifically Costs and Benefits are assesses with respect to the aspects shown in the following tables,

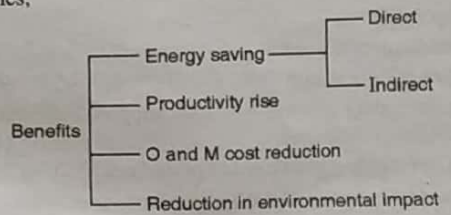

Fig. 5.5.9 : Various benefits to be assessed

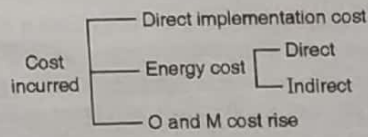

Fig. 5.5.10 : Various cost to be assessed

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(f) Report Writing

- Report writing is an important step between actual audit and implementation phase.
- Audit bindings are described in lucid way that encourages to take the actions applicable to all levels.
- Data required for this includes results from each step of previous stages right from the initial analysis.
- A brief and gripping audit report specifies,

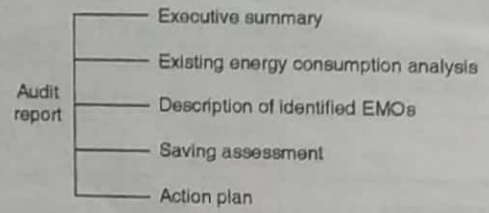

Fig. 5.5.11 : Major contents of Audit report

5.5.1.3 Post audit / Implementation Phase

- Post audit phase includes preparation and implementation of action plan.
- An implementation of action plan defines a procedure to ensure successful realization of suggested improvements.

  It specifies,
  - Clear goals – Resources
  - Targets for saving
  - Roles and responsibilities
- Action plan can be updated on the certain intervals to reflect achievements by now, performance changes and shifting of priority if any.
- Implementation of plan mainly requires personnel support. This can be achieved by providing support for energy efficiency initiatives.
  - **Training** that provide best practices and procedures
  - **Encouragement** by incentives on energy performances.

5.5.2 Understanding the Energy Costs

- Having the knowledge of factors contributing to energy costs is essential as it not only increases the awareness but also helps in the saving calculations.
- Many industries or facilities may not have meters at each and every energy consumption point to measure energy use. Fuels invoices and electricity bills prove useful in such cases.
- It is important to analyse the costs incurred in energy with respect to the production. The annual balance sheet of the company includes such information of fuels costs and power related to the production. These can also be used.

- Energy invoice provides useful information that includes following;
  - **Record of historic data** of energy purchased in a particular year. This helps in setting a baseline for reference in future for further use.
  - **Potential for savings :** energy invoices which are directly related to production needs may reflect potential for savings.
  - The duration of energy transaction on the basis of maximum demand tariff.
  - It may indicate the areas where savings can be made.
- Energy invoices are also helpful in quantifying the energy and financial savings due to implementation of energy conservation measures in after years.
- It is also important to keep a track of progress and monitoring in this phase.
- Major contributions in the fuel costs are,
  - Cost of fuels required to supply thermal energy demand and
  - Electrical power cost

(a) Fuel Cost

- Many fuels such as Fuel oil, Light Diesel Oil (LDO). Liquefied Petroleum Gas (LPG), Coal, Lignite, Wood, LECO fines, etc are available to provide thermal energy.
- Solid fuels such as coal, wood is purchased in Tons and liquid fuels in Kilolitres.
- Essential considerations for the purchase of fuel are
  - Availability
  - Cost
  - Quality
- Analysis of energy efficiency and economics is important for procurement of fuel.
- Significant aspects taken into account related to economics are
  - Price at source
  - Means of transport
  - Transportation cost
- And key factors regarding energy efficiency are
  - Quality of fuel
  - Energy content
- Consideration of the quality of fuels refer to the analysis if the fuel is contaminated or check if includes moisture.
- Calorific value may decide the energy content and hence efficiency of the fuel.

(b) Power Cost

- Power cost refers to the electricity cost. Electricity though has same function, its cost varies state wise, city wise, consumer wise.
- Many factors contribute in the final price of electricity such as kVA, kWh, Peak/Non peak period, Power Factor on which Maximum demand charges, Energy charges, TOD charges, Power factor charge depends respectively.

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- In addition it may include incentives and penalties.
- Various categories of consumers i.e. commercial, residential, industrial, government, agricultural are applied various types of tariff clauses and rates.

Example

Following table shows a sample summery of all forms of energy purchased in an industry prepared on the basis of their invoices.

Table 5.5.1: Summary of Energy invoices

Type of energy	Units consumed	Charge	Monthly bill (Rs)
Electricity	4,50,000 kWh	Rs. 4.5 / kWh	20,25,000
Fuel Oil	300 kL	Rs. 12,000 / kL	36,00,000
Coal	1000 tons	Rs. 2200 / ton	22,00,000
		Total	78,25,000

- Transaction of every different form of energy is done in different unit. For example electricity is charged per kWh, coal is charged per tonne, fuel oil is charged per litre.
- It makes their comparison difficult and this problem is resolved by converting them into a common unit. Some commonly used energy units are kWh, Giga joules, kCals etc.

Electricity (1 kWh) = 860 kCal/kWh (0.0036 GJ)

Heavy fuel oil (Gross calorific value, GCV) = 10000 kCal/litre (0.0411 GJ/litre)

Coal (Gross calorific value, GCV) = 4000 kCal/kg (28 GJ/ton)

5.5.3 Benchmarking

5.5.3.1 What is Benchmarking ?

- Benchmarking is an effective tool for the performance evaluation and the justifiable gradual development of the ways of the improvement of (industrial) unit.
- Benchmarking can be internal and external.
- Internal benchmarking refers to the historic or trend analysis.
- Proper documentation of the historical data helps to sketch the trend of energy consumption and cost incurred on monthly or daily basis.
- Trend analysis of major factors such as energy guzzler areas, costs and specific energy consumption is very important in order to understand how capacity utilization impact on the efficient energy use and costs comprehensively.
- External benchmarking is nothing but a comparison between units among a set of similar units.
- However, settlement of similarities is important among these, unless it would lead to an error in findings.
- Following are some key factors that need to be observed essentially referred to an external benchmarking in an industrial unit.
  - A set of desired levels in operations.
  - Age of the technology
  - Specifications and quality of raw material as well as product.

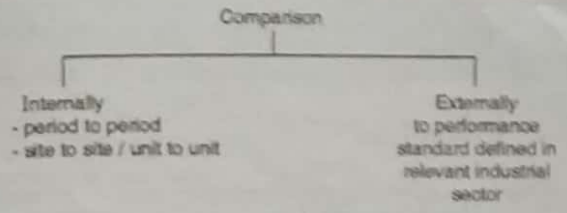

Fig. 5.5.12 : Internal and External Benchmarking

5.5.3.2 Benefits of Benchmarking Energy Performance

- Energy consumption may be fixed or variable. Benchmarking helps to quantify this energy consumption trends with respect to production output.
- It helps to increase the capacity utilization by analyzing the energy performance of the industrial plant at various production levels.
- It brings in notice the best practices to be adopted in the plant by using external benchmarking data.
- It identifies the possibilities and scope to reduce the energy consumption as well as cost and discover the margin.
- It contributes to monitoring and targeting practices by laying a basis.

5.5.3.3 Benchmark Parameters

- The benchmarking parameters can be related to gross production, equipment or utility. These parameters vary industry to industry. Few examples for particular industrial plant and their benchmarking parameters are mentioned in following tables.
- Also, it is important to mention and consider some other process related essential parameters alongside benchmarks in order to obtain a comprehensive comparison.

(a) Gross output production related parameters:

Sr. No	Industrial Plant	Benchmark parameters	Related important parameters
01	Cement	kWh/MT clinker	- Type of cement - Fineness (Portland and Process used)
02	Textile	kWh/kg yarn	- Average count - Type of yarn (Polyester / Cotton)
03	Paper	kWh/MT, kCal/kg. paper	- Type of paper - Raw material - Extent of recycling - GSM quality

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Sr. No	Industrial Plant	Benchmark parameters	Related important parameters
04	Power Plant / Cogeneration Plant	kCal/kWh Power	- % Loading on Plant - Condenser vacuum - Temperature of inlet cooling water
05	Fertilizer	Million kilocals/MT Urea or Ammonia	- % capacity utilization - on-stream factor
06	Foundry	kWh/MT of liquid metal	- Melt output - Type of furnace - Mix of raw material - Composition (mild steel, high carbon steel/cast iron etc.)

(b) Equipment / Utility related parameters

Sr. No	Equipment / Utility	Benchmark parameters	Related important parameters
01	Air conditioning plant	kW/ton of refrigeration	- Temperature level of chilled water - Refrigeration load (TR)
02	Boiler plant	Thermal efficiency (%)	- Quality of fuel - Type of fuel - Temperature - Steam Pressure - Flow of steam - Method of heat loss computation (Direct/Indirect)
03	Cooling tower	Effectiveness (%)	- Dry/Wet bulb temperature of ambient air - Relative humidity - Circulating air/water flow
04	Diesel power generation plant	kWh /litre	- Similar % Loading on Plant - Steady run
05	Compressor	kWh/NM3	- Similar temperature and pressure of inlet air

5.5.4 Maximizing System Efficiencies

- There are many factors that may contribute directly or indirectly to the inefficiency in the system. Therefore, ways and exercises for maximizing the efficiency may vary depending upon the context.

- A general course of action towards increasing the efficiency includes,
  - **Energy matching:** Matching of energy usage and sources
  - **Operation and maintenance:** Observe the best available and most appropriate practices in operation and maintenance.
  - **Use new technology:** Adoption of latest and judicious technology.
  - **Minimize input:** Focus on the curtailment of input energy by minimizing its need using various measures.
  - Fuel Substitution
- One of the major reasons of inefficiency in any industrial plant is mismatch between the equipment capacity and user's requirement.
- This inefficiency is an outcome of part load operations and wastage of energy caused by mismatch.
- There are many practices that elegantly emerge as practices for a matching of an equipment capacity and end use need.
- Characteristic of the system is due to its design. System designer takes the responsibility for the same.
- Whereas, system optimization is energy auditors job.

5.5.5 Fuel and Energy Substitution

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- Any production process or system consumes the energy as a major input.
- Non renewable and fossil fuels supply 85% of primary energy.
- Reducing the energy dependency is one of the major objectives of energy audit. It is possible to achieve by following two effective ways.
  - **Energy conservation**
  - **Fuel/Energy substitution**
- Energy conservation reduces the extent of dependency on fossil fuels by curtailing the energy needs.
- The term energy conservation includes various practices and procedures adopted with the motive of minimizing the total amount of present energy consumption of the plant.
- There are three key aspects essential to be considered while selecting a fuel for a particular use.
- Quality of the fuel (to obtain maximum efficiency) Cost
- Environmental harm
- Fuel / Energy substitution is the replacement of the existing fuel / energy input with the fuel of more efficiency, less cost and minimum environmental impact.
- Natural gas and biogas are gaining popularity as a better option to substitute the existing fuels.

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Table 5.5.2 : Examples of fuel / energy substitution

Sr. No.	Existing fuel/energy	Substitute fuel/energy
01	Soft Coke	Kerosene, Liquefied Petroleum Gas (LPG)
02	Coal	Coconut shell, rice husk
03	Light Diesel Oil (LDO)	Low Sulphur Heavy Stock (LSHS)
04	Electric heaters	Steam heaters
05	Steam based hot water system	Solar based thermal system

5.6 Instruments and Equipments used in Energy Audit

- An energy auditor should be well familiar with measuring instruments in order to have knowledge of purchase, rent and most important use of particular instrument.
- Basic need to obtain the useful measurement data for energy audit is proper selection and use of the instrument.
- The most usual measured quantities during an auditing session are :
  - Liquid and gas fuel flows.
  - Electrical measurements, such as the voltage, current intensity, kVA, kW, kVAR, power factor, frequency.
  - Temperatures of solid and liquid surfaces.
  - Pressure of fluids in tubes, furnaces or vessels (including measurements under evacuation conditions).
  - Exhaust gases emissions and contents in CO_2, CO, O_2 and smoke.
  - Relative humidity.
  - Luminance levels.
- The auditor has to specify from the beginning a list of all required instrumentation, either available or not and/or portable or not, in order to conclude the auditing process.
- The commonly found instruments in the energy auditor's toolbox are,
  - Electric power meter
  - Combustion analyzer
  - Digital thermometer
  - Infrared thermometer
  - Psychrometer (humidity measurement)
  - Airflow measurement devices
  - Tachometer
  - Ultrasonic leak detector
- Some instruments can be used on-line i.e. without switching off the process.
- Hand-held instruments could be used for instant measurements.
- Digital meters (DMs) are taking the place of conventional analogue ones due to comparatively lower cost and simplicity in use. Accuracy of the DMs is much more than normally required for energy audit.
- Some advanced types of instrument can be used for taking reading as well as printout of the readings at required intervals.

5.6.1 Electric Power Meter

- Electrical power measuring instruments prove convincing and convenient tool for the energy auditor.
- Power meters bring in view the locations and ways of power and energy consumption and focus a light on how other forms of energy are being consumed by equipments.
- Advanced technology has made energy auditor able to measure electrical power into watts with single instrument that avoids inconvenience due to separate meters and measurements of Voltage, Current and Power Factor for the same.
- All these functions are combined together in the latest handy wattmeter.
- Handheld Digital wattmeter (Single Phase / Three Phase) is shown in Fig. 5.6.1.
- Two contact probes are used to measure Voltage and a clip on current clamp measure Current in the Single Phase Wattmeter.
- A typical meter is illustrated in Fig. 5.6.1.

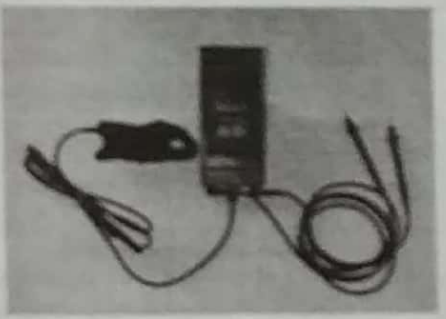

Fig. 5.6.1 : Handheld single-phase digital wattmeter

- Voltage up to 600 V and current up to 200 A can be measured with the shown configuration. These meters can be made to handle current up to 30 to 3000 A if used with flexible current transformer.
- These instruments are primarily intended for measurements in single phase circuit though it also has functionality which makes it possible to use for measurements on three phase balanced systems.
- Typical connections are illustrated in Fig. 5.6.2 and 5.6.3.

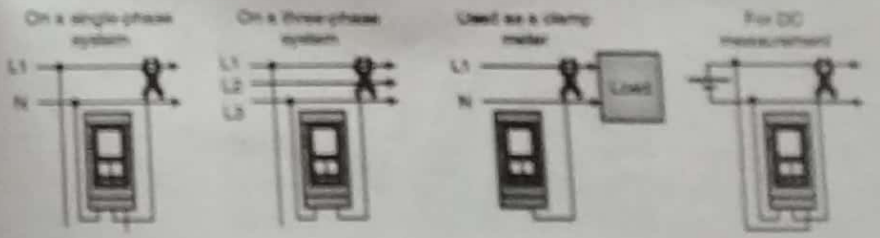

Fig. 5.6.2 : Typical Connection for single-Phase wattmeter

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- For true measurements on three-phase systems, depending upon whether the system is three- or four-wire, two- or three-phase currents and three-phase voltages must be measured.

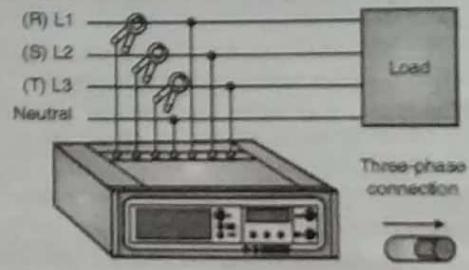

Fig. 5.6.3 : Three-Phase typical Connection

- Handy power measuring instrument supports measurements of more than 30 parameters such as voltage, current, power- Active , Reactive and True, Imported and Exported Energy.
- Beyond basic power measurement these type of meters support,
  - Measurement and analysis of power quality parameters including harmonics.
  - Data hold and allows real time comparison of new readings against stored values.
  - Suitable for DC measurement (via optional DC clamp).
  - Optional inputs for recording of other parameters such as temperature.
- **Applications**
  - To establish a Demand Trend of a facility or a substation.
  - Specific equipment or manufacturing process in a plant or a system.
  - Measure and record readings at individual loads. For e.g. single or three phase motor loads.
  - Characterization of a process by measuring consumption outline for a sample interval.

5.6.2 Combustion Analyzer

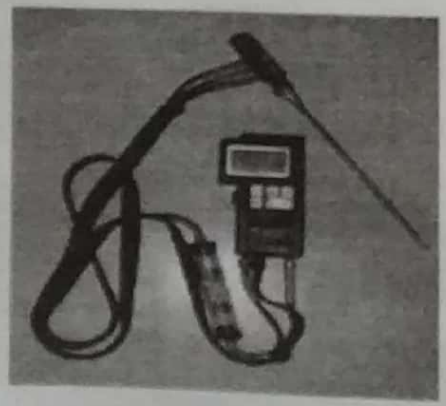

Fig. 5.6.4 : Electronic Combustion Analyzer

- Latest combustion analyzers are portable electronic instruments used for the measurement of combustion efficiency of boilers, furnaces.
- Combustion analyzer is essential to ensure the optimum ratio of air to fuel used.
- Electronic combustion analyzer includes many measurements in one unit, mostly battery powered and digital display with keypad for user.
- A basic analyzer supports measurement of
  - Flue/ Stack gas temperature
  - Combustion Air Temperature
  - Oxygen Level
  - Carbon monoxide Level
- Typical combustion analyzer is shown in Fig. 5.6.4 useful for testing boilers, plant heating equipments and some process combustion systems, etc.
- Applications- Boilers, Unit Heaters, Hot water heaters, Heating as well as process furnaces, Process ovens, dryers, Pre-heaters, etc
- Advanced meters of these kinds have features of alarms, multiple gas analysis, integration with printers, etc.

5.6.3 Fuel Efficiency Monitor

- Fuel efficiency monitor helps in determining combustion efficiency.
- Oxygen and temperatures of the flue gases are measured.
- Microprocessor calculates combustion efficiency on receiving calorific values of fuels.

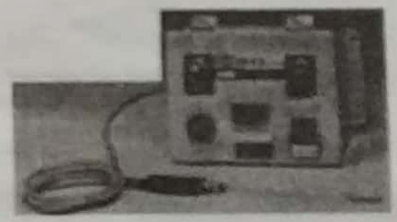

Fig. 5.6.5 : Fuel efficiency monitor

5.6.4 Flue Gas Analyzers (Fyriter)

- Flue gas sample under measurement is suctioned using a hand bellow pump in fyrite which already includes a solution.
- Liquid volume changes as the gas reacts and the amount of gas is revealed. O_2 and CO_2 can be measured separately with separate fyrite.

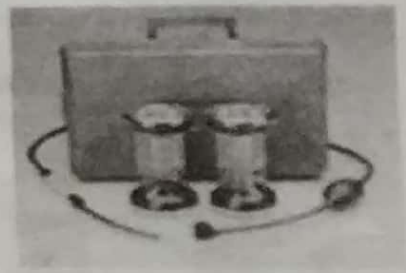

Fig. 5.6.6 : Flue gas analyzer

5.6.5 Thermometers

- Temperature measurements help the quantification of used thermal energy as well as the various losses.
- Commonly measured temperatures: Temperatures of Air, gas, fluid and surface.

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- Some temperature measurements may be contact type and others may be using non-contact or radiation-based measurements.

(a)	Contact Thermometer
(b)	Infrared Thermometer

(a) Contact Thermometer

- Contact thermometers can measure temperature of hot water, hot gases and hot air as well. Probes are positioned in the flow of temperature is to be measured. Leaf type probes are suitable for temperature measurement of surface.
- As can be seen in figure 5.6.7 assembly for temperature measurement by thermocouple based device includes,
  - Thermocouple probe accommodated in a stainless steel sleeve
  - A digital Display
- Output voltage at the junction can be observed in terms of temperature reading at Digital display.

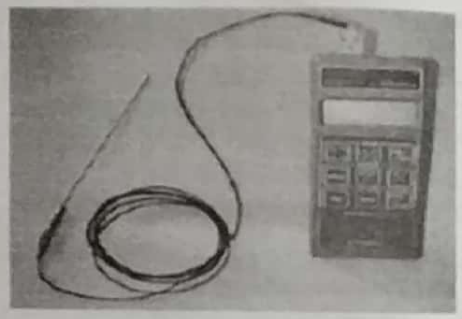

Fig. 5.6.7 : Thermocouple-Based digital thermometer

(b) Infrared Thermometer

- Infrared thermometer belongs to non contact type of thermometers.
- It gives the temperature readings directly at the display when it is directed towards heat source.
- Infrared thermometer is useful especially in applications like measurement of hot spots in motors, transformers and also surface temperatures etc.

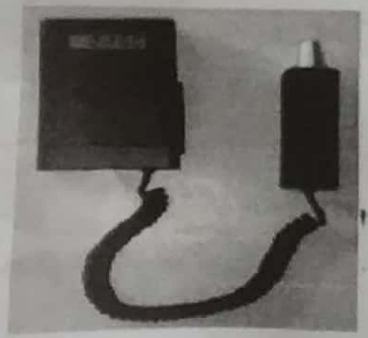

Fig. 5.6.8 : Infrared temperature-Measuring device

5.6.6 Airflow Measurements

- Airflow measurements are very necessary to analyze the HVAC and exhaust systems.
- Accurate airflow measurement is normally difficult and it demands the specialized instruments.
- Some of the simple to operate instrument for basic energy audit are,

1. Digital Vane Anemometer

- It employs a rotating vane whose speed varies directly with the air speed.
- Use of this instrument is restricted because its size which imposes difficulty in putting the sensor in the air stream to be measured.
- Not suitable for In-Duct measurements.

2. Digital Thermo Anemometer

- Hot wire is cooled in the air stream. This temperature of wire is sensed to sense the speed.
- Suitable for ducts.

3. Pitot Tube and Manometer

- This is the most versatile instruments for airflow measurement.
- Handheld digital manometers are available having data logging functions for advanced applications.
- Pitot tube - Manometer offers the advantage of measurement of necessary pressure required for assessment of power.

5.6.7 Water flow Meter

- It works on the Doppler Effect and a non contact type of flow meter.
- Transmitter and Receiver housed on the opposite sides of the pipe sends and receive signal respectively and gives output.

Fig. 5.6.9 : Water flow meter

5.6.8 Speed Measurement

- Energy auditor requires tachometer to measure the speed of motor or driven device.
- Tachometer proves useful when it comes to compare the name plate and specifications mentioned on fan, pump, etc. to their actual performance.
- **Contact Type**
  - A simple tachometer is contact type. It is used where direct access is possible.
  - It is connected at the end of rotating shaft.
  - Can also be connected against the conveyor belt to determine linear speed.
- **Non Contacting Type**
  - More sophisticated and safer ones are non-contact instruments.

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- It throws a light beam on rotating shaft which is reflected off from a reflective patch on the shaft.

- To compare the actual performance of fan, compressor, pump with that specified on the nameplate speed measurement is an important aspect.

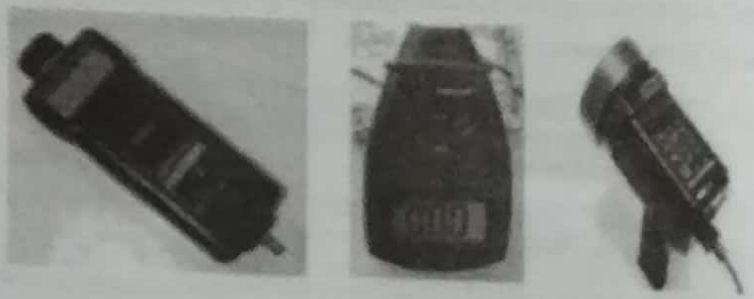

Fig. 5.6.10 : Tachometer

5.6.9 Leak Detectors

- Detection of the minute leaks in compressed air and other gases are humanly impossible. However, it can be done using ultrasonic instruments.
- Ultrasonic sound id generated when a gas leaks way in a pressure or vacuum system
- Directionality of this sound is used to locate the source of leak.
- The ultrasonic leak detector is sensitively tuned to this frequency of sound.
- Strength of leak signal is indicated by a display. Adjustable sensitivity helps to pinpoint the leak location
- Fig. 5.6.11 shows ultrasonic leak detector with the ultrasonic transmitter. This is appropriate to check the air leaks around the door and window seals and gaskets, water leak in roof and leaks of vacuum vessels.
- **Applications:** Refrigeration and Air Conditioning System, Heating System, Compressed Air Systems, etc.

Fig. 5.6.11 : Ultrasonic Detector with Transmitter

5.6.10 Lux Meters

- Lux meters are used for the pupose of measurement of illumination levels in the facilty.
- It is made up of a photo-cell to senses the light output. Photo cell converts this light output to electrical pulses which are calibrated as lux.
- It proves useful for comparing the actual lux level with the recommended standards for particular areas.
- A basic Lux meter is as shown in figure. It has features such as,
  - Measurement from 0 to 50,000 lux
  - It has sensor in a separate unit from display, connected with flexible cord.
  - It gives accuracy near about 5 %
  - Automatic Zero Adjustment
  - Battery Operated.
- Along with these a very useful feature of analog output functions for recording.

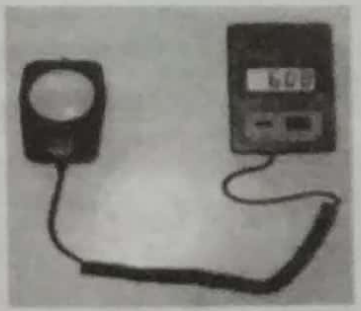

Fig. 5.6.12 : Basic Light Meter

5.6.11 Compact Data Logger

- Data logger is an electronic recording instrument.
- Various measurements such as voltages, temperatures, light intensities, relative humidity or ON/OFF states over the time are recorded in the data logger.
- Compact data logger offers the advantage of quick and easy data collection from number of sensors and instruments to the energy auditor.
- Typical Data Logger consist of,
  - Microprocessor
  - Memory that stores data
  - Sensor or multiple sensors (Internal/External)
  - Battery to power
- Data loggers comes with a provisions of,
  - Interfacing with PC
  - Software which can configure as well as retrieve the collected data.

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- **Applications**
  - Temperature and humidity and illumination level logging with internal sensors.
  - Event logging such as motor, lights or heater on/off events, etc.

Part II : Electrical Energy Performance Assessment

5.7 Electrical Motors

- Motors are by far the most important type of electric load. They are used in all sectors and in a wide range of applications.
- Electric motors use over half of all electricity consumed in most countries. Typically 60-80% of the electricity, which is used in the industrial sector and about 20-35% of the electricity used in the commercial sector is consumed by motors.
- Efficiency and loading are the key performance terms that are important to understand regarding the motor.
- **Motor efficiency** is the ratio of mechanical work done by motor to the amount of electrical energy consumed to do so.

$$\eta = \frac{P_{out}}{P_{in}} = 1 - \frac{P_{loss}}{P_{in}}$$

Where,

P_{out}- Mechanical output power

P_{in}- Electrical input power

P_{loss}- losses

- **Motor loading** is the ratio of actual load on motor on which it is operating to the rated capacity of the motor.

$$\text{Motor loading \%} = \frac{\text{Actual operating load of the motor}}{\text{Rated capacity of the motor}} \times 1000$$

- Normally, motor efficiency and loading both are expressed in terms of percentage.
- As far as energy performance of the motors is concerned, the motor efficiency and power factor are the parameters of prime importance.
- Energy losses are the decisive factors in the motor efficiency.
- The key factor in the efficient operation of the motor lies in the appropriate selection of the motor according to its use.
- The motor operates at constant efficiency in the range of 80 to 100 % for the loading between 50 to 100 %. (Observe the graph)
- The motor is said to be undergoing a part load operation when it runs on the load much lower than its rating.
- Therefore, it is highly recommended to replace the partly loaded higher rated motor with the small motor that can run at full load to improve the efficiency.

Name	Percent of total loss	Description	Fixed or variable	How to reduce
Core losses	15-15%	Energy required to magnetize core	Fixed	Improved permeability steel, lengthening core, using thinner lamination in the core
Windage and friction	15-15%	Losses due to bearing friction and air resistance, which is primarily caused by the cooling fan.	Fixed	Lower friction bearings, improve fan design and air follow.
Stator losses	25-40%	Heating due to current flow through the resistance of the stator winding.	Variable	Increasing the volume of copper wire in the stator, through improved stator slot designs, and by using thinner insulation.
Rotor losses	15-25%	Hearing due to IR losses in the rotor conductive bars.	Variable	Increasing the size of rotor conducting bars and end rings to reduce resistance.
Additional load losses	10-20%	Leakage fluxes induced by load currents and various other minor losses.	Variable	Various design and manufacturing details.

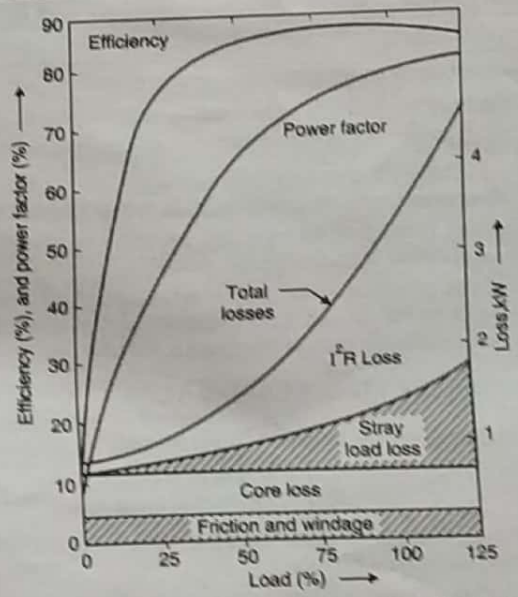

Fig. 5.7.1: Variation of motor losses, motor efficiency and power factor with the percentage loading

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5.7.1 Testing Standards

- Several motor testing standards have been developed by various standards institutes around the globe. These standards prescribe particular practices of testing;
  - Test equipments to be used
  - Motor run time before conducting the test
  - Method of load application
  - Data to be collected
  - Method of losses measurement
- Motor testing protocols vary around the world. The most popular of them are;

Table 5.7.1: Motor Testing Standards

Europe	International Electro technical Commission	IEC 60034-2
		IEC 61972
USA	Institute of Electrical and Electronic Engineers	IEEE 112- Method B
USA	American National Standards Institute	C50.20
USA	National Electrical Manufacturers Association	MG1-12.58.1
Canada	Canadian Standards Association	CSA Standard 390
Japan	Japan Industrial Standards	JEC 37
Great Britain	British Standards	BS- 269

- Application of these protocols on any given motor results in different values of efficiency.
- This difference may be up to 3%.

5.7.2 Efficiency Testing

- There are two methods of efficiency measurement of the motors namely **Direct and Indirect**.
- Though, direct methods offers great accuracy they are yet to be widespread due to associated higher costs of required testing laboratory set up.
- Measurement of input power is quite simple as compared to measurement of output. Measurement of output which can also include measurement of losses that not only demands furnished testing facilities but also requires lot of efforts and time.

5.7.2.1 Direct Methods (IEEE 112-B, CSA-390)

- The efficiency of electric motor can be directly found out using the equation,

$$\text{Efficiency \%} = \frac{\text{Mechanical output power}}{\text{Electrical input power}} \times 100\ \%$$

- Measurement of output power (mechanical) and input power (electrical) is required to make use of this equation to find out motor efficiency.
- Input electrical power can be measured with the help of a simple set up which does not includes costly equipments and apparatus.
- Next, the output mechanical power is given by the equation:

$$\text{Mechanical Power} = \text{Torque} \times \text{Angular Speed}$$

- In this, speed is measured with the help of digital tachometers that gives accurate readings. It has a simple procedure to use and is affordable as far as cost is concerned.
- However, the major and complicated part is measurement of torque. Torque measurement essentially requires a more elaborate set up with expensive equipment and apparatus to get accurate results.
- Motor is coupled to a dynamometer that offers a controllable variable load.
- Dynamometer is an instrument that maintains a constant torque resistance, allowing motor load to be calculated.
- As the load varies, change in torque is reflected as it comes equipped with an accurate torque transducer.

5.7.2.2 Indirect Methods (IEC 34-2, JEC-37)

- Indirect method overcomes the two major issues of direct methods viz. Complexity and expenses incurred in the measurement of the torque.
- The efficiency of electric motor can be indirectly found out using the equation:

$$\text{Efficiency \%} = \frac{\text{Electrical input power} - \text{losses}}{\text{Electrical input power}} \times 100\ \%$$

- It can be observed from the equation that it is necessary to measure the losses occurring in the motor to calculate efficiency by the indirect method.

(a) Core and F and W Losses

- The **no load test** on IM gives information regarding no load losses. This test is performed at rated frequency and voltage without applying the load on shaft.
- At no load motor current is very small (just to produce sufficient torque to overcome the F and W losses) therefore the no load rotor I^2R loss is too small.
- However, no-load stator I^2R loss of an induction motor may be significant owing to its larger exciting current.

$$P_{\text{core-F\&W}} = P_{NL} - (I_{NL})^2 \times R_s$$

Where,

$P_{\text{core-F\&W}}$ - Core and Friction and Windage (F and W) losses

P_{NL}- No load input power (in Watts)

$(I_{NL})2$- No load current

R_s- Stator resistance

- The readings of no load input power are taken at variable voltages to separate core and F and W losses.
- Intercept on the plot between no load input power and voltage is the F and W loss component.

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(b) Stator and Rotor I^2R losses

- Accurate measurement of stator and rotor resistance is important for the calculation of stator and rotor I^2R losses.
- In this, bridge or volt amp method is used to measure the resistance of stator winding.
- Modern motors operate between 100°C to 120°C temperature. Correction of the resistance to this temperature is necessary for accurate calculations. The correction factor is given by the expression;

$$\frac{R_2}{R_1} = \frac{235 + t_2}{235 + t_1}$$

Where,

t_1- ambient temperature

t_2- operating temperature

- Rotor I^2R losses are measured by;

Rotor I^2 R losses = Slip × (Stator Input – Stator I^2 R Losses – Core Loss)

- This expression requires accurate measurement of slip. Stroboscope or Non contact tachometer is used to measure the slip.

(c) Stray load Losses

- Accurate measurement of these losses is hard amongst all losses.
- The method prescribed by IEEE standard 112 for the measurement of these losses is too complex to adopt on shop floor. IEEE standard 112 has stated values of stray load losses for various motor ratings as in following table.

Motor Rating (HP)	Stray Losses (%)
01 – 125	1.8
126 – 500	1.5
501 – 2499	1.2
2500 and above	0.9

- Whereas, IS and IEC standards simply consider a fixed value of 0.5 % of the motor output power. However it is probable that stray losses would be more than this.

5.7.3 Comparison of Testing Standards

- From the above discussion we can conclude that exact calculation of the efficiency is very difficult. Various motor efficiency testing protocols have specified various methods or values to be taken for the stray load losses which obviously leads to difference in estimation of motor efficiency.
- The calculated efficiency may vary: for same motor with different testing standards or same testing standard with different manufacturers of motor.
- Following Table 5.7.2 explains the result of various testing standards on the same set of motors.

Table 5.7.2: Efficiency determined by different standards

Rating (HP)	JEC – 37 Circle diagram	IEC 34 – 2 Loss summation	IEEE – 112 Method B
05	88.8	88.3	86.2
10	89.7	89.2	86.9
20	91.9	91.4	90.4
75	93.1	92.7	90.0

Source: R. E. Osterlei, Proceedings of the National Conference on Power Transmission, Gould Inc., St. Louis, MO, 1980.

5.7.4 Motor Loading

- As discussed in the introductory part of this chapter motor loading is one of the major parameter that has a crucial impact on the efficient operation of the motor.
- There are three methods of determining the motor loading as in following sections.
  1. By measuring input power
  2. By measuring line current
  3. Slip method

(1) By measuring input power

- The equation to find out loading by this method is,

$$\text{Load} = \frac{P_i}{P_{IR}} \times 100\ \%$$

Where,

P_i = input power in kW (measured by any power meter)

P_{IR} = input power with respect to the full rated load in kW

Here,

$$P_{IR} = \frac{\text{Full rated kW (mentioned on the name plate)}}{\eta\ FL}$$

- Rated kW and Efficiency can be noted from the specification plate on motor.
- This rated kW on the motor specification plate is referred to the output condition.

(2) By measuring line current

- Wherever input power measurement is not possible and facility for current measurement is available, the line current method is used for the loading estimation.

$$\%\ \text{Load} = \frac{\text{Load current}}{\text{Rated current}} \times 100$$

- Load current is amperage draw of a motor and rated current can be found on specification plate on the motor.

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- Normally load current shows the linear relation with the applied load upto 75% of the full load.
- However, as the applied load goes below 75%, due to decrease in power factor non linearity is introduced amperage curve and increases so on.
- This method is not suitable for the operation in the low load region of the amperage curve as load current is non-linear with respect to the load in that region. However, this method may prove useful in the initial stages to discover the oversized motors.
- Reader should note the major limitation of applicability of this method **only up to 75% loading.**

(3) Slip method

- This in another method, which can be used where power measurement facility is not available.
- Loading is estimated by calculating slip in this method.
- It requires a tachometer for the measurement of the speed in order to find out slip.

$$\text{Load} = \frac{\text{Slip}}{S_s - S_r} \times 100\%$$

Where,

S_s – Synchronous speed in RPM

S_r – Full load speed in RPM (mentioned on plate)

Also we know

Slip = Synchronous speed – Measured speed (in RPM)

- This method offers the advantages of simplicity as well as safety.
- In addition, most of the motor comes with the little extended shaft to make it accessible to connect the tachometer or to facilitate the use of stroboscope.
- However, this method also **suffers from the limited accuracy** like the previous one.
- Calculations of slip method depend on the difference between full load speed (mentioned on nameplate) and synchronous speed. And generally it happens that manufacturer report the full load speed in round figure (mostly in the multiples of 5 RPM). The rounded up speed though seem minor, it introduces considerable error in the calculation of the slip and hence the loading estimate.
- In addition, there is an inverse relation between slip and square of the terminal voltage. This again necessitates the voltage compensated load calculation. It is given by

$$\text{Load} = \frac{\text{Slip}}{(S_s - S_r) \times (V_r/V)^2} \times 100\%$$

Where,

S_s – Synchronous speed in RPM

S_r – Full load speed in RPM (mentioned on plate)

V – RMS voltage (mean line to line)

V_r – Rated voltage (mentioned on nameplate)

5.8 Variable Speed Drives (VSD)

- The most popular method nowadays for regulating the speed of driven equipment is variable frequency drive.
- It is gaining wide acceptance over the other conventional methods like gear boxes, variable pulleys, etc. VFD achieves the speed control by varying the frequency and voltage
- The concept of VDF is explained in the section 6.6
- Successful implementation of the variable speed drives depends on following key factors viz.
  - Type of Load
  - Motor information
  - Efficiency and power factor
  - Protection and Power quality

(1) Load type

- The application is a decisive factor to choose the Proper VFD. The applications where VFDs are implemented demands either of Variable torque or Constant torque. It regulates the appropriateness of the VFD.
- **Variable torque drives**
  - Fan, pumps, etc are examples of centrifugal applications. For these particular applications variable torque VFDs prove to be the appropriate selection.
  - The need of energy saving stimulates the installation of variable torque drives for these applications.
  - A fan is the most suitable example of centrifugal application. It requires less torque to run at 50% speed compared to when it runs at its full speed.
  - Variable torque drives enables the motor in such centrifugal applications to apply only the necessary torque. Application of the required torque avoids the wastage of energy.
  - The chances of exceeding the current are less in constant torque VFDs therefore, an **overload current capacity of 120%** for a minute is considered to be sufficient.
- **Constant torque drive**
  - Applications such as conveyers, punch press, positive displacement pumps, etc requires the constant torque at any speed on the contrary to the centrifugal applications. Here constant torque VFDs prove to be the appropriate selection.
  - The overload current capacity of the constant torque VFDs is required to be more i.e. **150% for a minute** as compared to the variable torque VFDs
- Accurate control of speed, torque and positioning is required in the case of tight process control.
- Use of sensor less vector drive or flux vector VFD is recommended here to achieve a high level of accuracy.

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(2) Motor Information

- Motor information is also one of the major factors in the selection of the VFDs.
- Some of the key motor information points include,
  - Full load amperage rating
  - Range of operating speed
  - Details if multiple motors
- **Full load ampere rating**

  Sizing of the VFDs on the basis of motor's HP rating introduces inaccuracies. Therefore, it is important to consider full load amperage rating.
- **Range of operating speed**
  - Running a motor below 20% of its rated maximum speed is not recommended as it may introduce heating issues.
  - Motor gets overheated if it is run (at the any speed less than this) without making the use of auxiliary cooling system with it.
- **Details of multiple motor**
  - **Full load ampere rating and Voltage rating** are the significant information of the motor that need to be considered while sizing variable frequency drives for controlling multiple motors.
  - Full load current rating of each motor should be summed up and all motors in a single VFD should have same voltage rating.

(3) Efficiency and Power factor

- **A full load efficiency of 95% or more** is desirable for variable frequency drives.
- Also power factor more than 0.95 is necessary under VFD operation. This power factor should not vary with different speeds.
- Maintaining the power factor more than 0.95 not only helps to minimize demand charges but also improves the equipment protection.

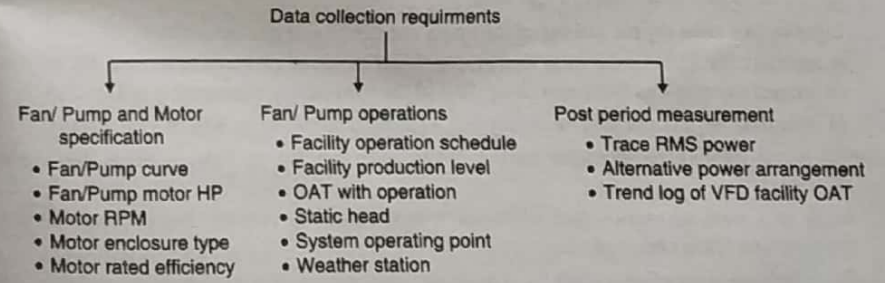
(4) Protection and Power quality

- Provision of motor overload protection is important to avoid instantaneous trip and motor over current.
- In addition, the various additional protection s are
  - Protection for over voltage and under voltage
  - Over temperature
  - Earth fault protection
- Desirable features of these protections are
  - Well arranged shut down of VFDs
  - Indication in the case of fault
  - Manual reset before start
  - Automatic restart in **the case of under voltage only** after recovering

  - **Memory-** to store the history of at least previous three faults so as to use in future.
- Some protections that operate externally such as
  - Circuit breaker
  - Motor circuit protector (MCP)
- Comprehensive study of the load pattern is essential to decide whether the subject equipment is an ideal candidate for the use of variable frequency drive.
- The equipment under consideration should be tested using power analyzer for
  - Number of operating hours
  - Various loading probabilities

5.8.1 Performance Curve Method

- Performance curve method is particularly suitable for variable-frequency drives (VFDs) installed at the commercial and industrial motor-driven centrifugal fans and pump. As discussed above their torque varies with speed.
- This method comes under International Performance Measurement and Verification Protocol (IPMVP) developed by EVO (Efficiency Valuation Organization)
- It's a part of Option A (EVO 2012) that includes Isolation Retrofit and Key Parameter Measurement.
- The method includes simultaneous measurement of
  - kilowatt of the VFD installed on the fan/pump
  - Outside Air Temperature (OAT) in the case of temperature sensitive load
  - Other parameters for e.g. Production or schedule.
- Energy savings are predicted on the basis of
  - Recorded power measurements
  - Performance specifications
  - Onsite operating characteristics of fan/pump
- Post installation flow trend can be developed on the basis of combined analysis of system specifications and observed power trend after the installation"
- Individual savings values from various sensitive parameters such as OAT (outside air temperature) to an annual profile can be added altogether to find annual savings.



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5.8.2 Information to Evaluate Energy Saving by VFDs

- Four basic aspects that help to determine the energy savings by the use of VFDs are
  - Method of flow control to which VFD is compared
  - Pump / Fan data
  - Process information
  - Efficiency of electrical apparatus

Method of flow control to which VFD is compared

- **Fan**
  - Dampers
  - Unrestrained flow
  - Inlet guide vanes / inlet dampers
- **Pumps**
  - Output throttling
  - Recirculation
- Eddy current coupling
- Two speed motors

Pump of fan data	Process information	Efficiency information of electrical apparatus
• Head Vs flow curve	• Specific gravity for pumps	• Motors
• Pump efficiency curve	• Specific density of of products	• Variable speed drives
	• System resistance head/flow curve	• Gears
	• Equipment duty cycle	• Transformer

5.9 Lighting System

- Besides aesthetic and decorative appearances, lighting plays a significant role in
  - Increasing the production
  - Fatigue reduction
  - Taking care of eyes and nervous system
  - Minimizing the count of accidents.
- Lighting is a most visible and one of the major sources of energy consumption
- It accounts for 15% of the total energy consumed in developing countries and 7% to 10% in developed countries, in India near about 20% of the total energy consumed is in Lighting.
- In Industrial and Commercial electricity bill, lighting accounts up to 30% of total amount.
- Advanced lighting technologies having better understanding of lighting needs are available nowadays.
- Light is a form of energy, and whenever a light source is switched on, proportional power consumption always takes place.
- Since lighting is supplied mainly by consuming fossil energy, it is important to employ efficient lighting.

5.9.1 Basic Terms Used in Illumination System

To design modern lighting schemes as well as selection of appropriate types of lamps and their fittings, knowledge of basic terms used in the field of illumination is very necessary. Important of them as follows :

(a) Light

- Light is defined as a part of the radiant energy from a hot body which produced the visual sensation upon the human eye.
- Denoted by-Q
- Unit- Lumen Hours

(b) Luminous Flux

- Luminous flux is defined as the total quantity of radiant energy emitted per second responsible for visual sensation from a luminous body.
- Denoted by - F
- Unit - Lumens
- Output and efficiency generally is specified by Luminous Flux.

(c) Illumination

- The process of hitting a ray of light upon any solid surface is termed as the illumination.
- Illumination may be defined as the total amount of lumens incident on the surface per unit area.
- Denoted by- E
- Unit- Lumens/square meter or Lux or Meter-candle.

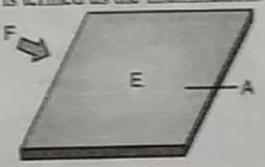

Fig. 5.9.1 : Illumination and Illuminance

$$E = F/A \text{ Lumens/m}^2$$

Where, F - Lumens incident

A - Surface area

- The degree of lighting produced by a lighting installation is often recognized by the illuminance produced on a particular plane.

(d) Lux

- Lux is defined as Luminous flux falling per square meter.
- It is an unit of illuminance.
- One Lux is equal to one Lumen per Square Meter.

(e) Maintained Illuminance

- The Average of Lux levels measured at various points in specified area is called as Average Maintained illuminance.

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- Maintained illuminance is a designated fixed level below which the average illuminance is not allowed to fall on any surface.
- It is a minimum illuminance at which operations such as lamp replacement luminaire cleaning, etc maintenance operations are carried out

(f) Circuit Watts

Circuit watt is the total power consumed by lamps and ballasts in a lighting installation under evaluation.

(g) Efficacy

The term efficacy is used in lighting to describe how efficiently electrical energy is converted into Light energy.

(h) Luminous Efficacy

- It is the ratio of Luminous Flux radiated by a lamp to the Input Power drawn by the lamp.
- Lamp efficiency = Luminous Flux / Power Input
- Unit- Lumen / Watt (lm/W)

(i) Lamp Circuit Efficacy

- A lamp emit particular amount of lumens for each watt of power it consumes. It is called as lamp circuit efficacy.
- Power consumed in lamp circuit = Power converted into light + Power loosed in control gear.
- It is the more appropriate measure for the lighting circuit having control gears.
- Unit - Lumens / Watt

(j) Luminaire

- A luminaire is an electrical device or light fixture used to create artificial light and/or illumination, by use of an electric lamp.
- It includes the complete lighting unit except light, which includes necessary parts required for fixing up the lamp and provide it a protection.
- Ballast, socket, lamp, reflector, wiring, diffuser, and housing.
- The term efficacy is used in lighting to describe how efficiently electrical energy is converted into Light energy.
- Luminaire is also termed as light fixture or generally a light fixture may include.
  - A fixture body
  - Socket to hold the lamp or facilitate replacement.
  - A switch to control
  - Reflectors
  - Ballast deep inside

(k) Colour Rendering Index (CRI)

- Sometimes it is also termed as Colour Rendition Index.
- Colour rendering index is a scale to quantify the ability of light source to impart colours of objects.
- CRI is determined by comparing with a set of standard colours or natural source.
- In applications such as photography light sources having high CRI is desirable.

(l) Installed Load Efficacy Ratio (ILER)

- The installed load efficacy ratio is the ratio of the average maintained illuminance provided on a horizontal working plane per circuit watt to the target illuminance on a horizontal working plane.
- Installed load efficacy ratio (ILER)

$$= \frac{\text{Actual Lux/W/m}^2}{\text{Target Lux/W/m}^2}$$

$$\text{Or} \quad \frac{\text{Target W/m}^2\text{/100 Lux}}{\text{Actual W/m}^2\text{/100 Lux}}$$

Lighting efficacy is reflected by the ILER

5.9.2 Procedure for Assessing the Existing Lighting System in the Facility

5.9.2.1 Purpose

- Mainly lighting is installed to meet the demand of an average illuminance on a horizontal plane.
- Lighting can be done throughout the interior or combined with general lighting in particular areas keeping the objective of providing maximum lighting by lowest power consumption.
- The reason behind the performing as assessment of the lighting installation is to calculate its efficacy in terms of Lux / Watt / m^2
- A lighting audit can give the efficacy of the installation as one of the outcome.

5.9.2.2 Pre Measurement Preparation

- All lamps should be with clean luminaries and working in condition.
- Light flow should not face any barrier to spread out within the interior, especially at measuring points.
- Accurate illuminance meter should be properly positioned and measurements should be taken at sufficient number of points within the interior to ensure accuracies of the readings.
- Surface should not offer obstacles or reflections to affect the measurements. It should be taken care of if any.
- If any old illuminance meter which is not checked from long time is there, it is recommended to calibrate that meter with the recent in-use meter so as to find a correction factor if required.

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5.9.2.3 Procedure for Lighting System Assessment

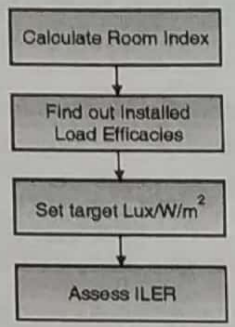

Fig. 5.9.2 : Procedure for assessment of lighting system

(1) Room Index

- Calculate the Room Index in order to determine number of points and their positions where measurements are to be carried out.

  Let,

  L_i - Length of interior

  W_i - Width of interior

  H_m - Height of the lighting fittings above the horizontal working plane.

- Then Room Index is calculated as,

$$\text{Room Index (RI)} = \frac{L \times W}{H_m (L + W)}$$

$$\text{Room Index (RI)} = \frac{Li \times Wi}{H_m (Li + Wi)}$$

The height of working plane is assumed as,

Place	Height of working plane above the floor (m)
Office	0.75
Manufacturing areas	0.85

- Minimum number of points of measurements is determined from,

Room Index	Minimum Number of Measuring Points
< 01	09
1 and < 02	16
2 and < 03	25
> 03	36

- The interior is split up into number of equal areas of maximum possible squares.
- Measurements of illuminance at the centre of each square are carried out and a mean is evaluated. Therefore, average illuminance on the horizontal working plane can be estimated.

(2) Finding out the Installed Load Efficacies

Step 1 : Measurement of the floor area of the interior.

Area = _____ m^2

Step 2 : Determine the Room Index by above formula.

RI = ----

Step 3 : Measure the total circuit watts of the lighting installation using power meter in case of dedicated feeder for lighting.

If real value is not known, a rational estimation is recommended and it can be obtained by summing up the wattages of total lamp with the ballasts count.

Total Circuit Wattage = ----

Step 4 : Value obtained in Step 3 / Value obtained in Step 1

Total circuit Watts / Floor Area = ---- W / m^2

Step 5 : Find out the average maintained illuminance using Lux Meter.

E_{av} Maintained = ----

Step 6 : Value obtained in Step 5 / Value obtained in Step 4

E_{av} Maintained ÷ W / m^2 = ---- Lux / W / m^2

Step 7 : Get target Lux / W / m^2 according to the type of Interior or Application and Room Index obtained in Step 2.

Target Lux / W / m^2 = ----

Step 8 : Installed Load Efficacy ratio (ILER) = Value Obtained in Step 6 / Value Obtained in Step 7

ILER = ----

(3) Target Lux / W / m^2 for Various Premises

- The amount of light required is an important factor to perform a particular task or to illuminate the workspace.
- The most effective lighting with respect to performance and cost needs to have detail knowledge of the premises or application for which it is to be installed.
- The primary requirements of lighting as well as quality and amount of illumination depend upon.
  - The nature of industry.
  - Its ocular needs and personnel.
- The best option for desired lighting is determined by
  - Details of floor and machines

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- Need for flexibility

The Chartered Institution of Building Services Engineers (CIBSE) recommends the target Lux / W / m^2 for maintained illuminance on horizontal plane for all room indices for various applications as in following Table 5.9.1.

Table 5.9.1 : CIBSE recommended Target Lux / W / m^2

Room index	Commercial lighting, (Offices, Retail stores etc.) and very clean industrial applications, Standard or good colour rendering. Ra : 40-85	Industrial lighting (Manufacturing areas, Workshops, Warehousing etc.) Standard or good colour rendering. Ra:40-85	Industrial lighting installations where standard or good colour rendering is not essential but some colour discrimination is required Ra:20-40
5	53 (1.89)	49 (2.04)	67 (1.49)
4	52 (1.92)	48 (2.08)	66 (1.52)
3	50 (2.00)	46 (2.17)	65 (1.54)
2.5	48 (2.08)	44 (2.27)	64 (1.56)
2	46 (2.17)	42 (2.38)	61 (1.64)
1.5	43 (2.33)	39 (2.56)	58 (1.72)
1.25	40 (2.50)	36 (2.78)	55 (1.82)
1	36 (2.78)	33 (3.03)	52 (1.92)

(4) Assessment of ILER using Indicators of Performances

- Calculated ILER is compared with the performance indicators as given in following Table 5.9.2.

Table 5.9.2 : Indicators of Performance

ILER	Assessment
0.75 or over	Satisfactory to Good
0.51 – 0.74	Review suggested
0.5 or less	Urgent action required

- It can be observed from the Table 5.9.2 that
  - No immediate improvements or modification is needed for the satisfactory ILER ratio of 0.75 or more.
  - Installation having ILER between 0.51 to 0.74 is required to be examined to find scope for possible improvements.
  - ILER of 0.5 or even less implies the need of immediate close analysis to discover the alternatives to transfigure the installation with the use of more efficient lighting equipments.

- Annual energy wastage is possible to calculate after deriving the actual ILER by the expression;

  Annual energy wastage (kWh) = (1 – ILER) x Total Load (kW) x Annual operating hours (h)
- Efficiency of the new lighting installations or replacement can also be assessed by comparison of ILE with the target value for Room Index and Type.
- In this case, if the calculated ILE is found less than the target value it is suggested to diagnose the reasons.

5.9.3 Recommended Luminance Levels

- As per IS 3646 all none working interiors should have at least 20 Lux illuminance.
- Scale of illuminance is recommended as 20-30-50-75-100-150-200-300-500-750-1000-1500-2000 Lux.
- Environment for which lighting is being installed may have different circumstances such as :
  - Different interiors for same applications.
  - Various conditions for same activity.
- Therefore, each type of interior or activity is recommended a three stepped range of illuminance. Higher Value (H), Middle Value (R), Lower Value (L).
- Which value out of three steps is to be applied is decided by particular conditions.
- Normally middle value (R) of each range is preferred level of illuminance that would be used unless specific conditions of Higher Value or Lower Value exist.
- The Higher Value (H) is suggested used when,
  - Task includes low reflectance or contrasts.
  - Rectification of errors is costly.
  - Visual work is critical
  - Accuracy or higher productivity is necessary to pay attention.
- The Lower Value (L) is suggested to use when,
  - Abnormally high reflectance or contrasts
  - Task may be executed occasionally.
- Following table shows the recommended illuminance for various activities as published by the Illuminating Engineering Society (IES).
- Tasks have been divided into 9 categories from A to I depending upon tasks which covers illuminance in the range of 20 Lux to 20,000 Lux.
- Categories to provide illuminance :
  - A - C : over a large area
  - D - F : for confined tasks
  - G - I : Extremely difficult visual tasks

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Table 5.9.3

Activity	Category	Lux
Public spaces with dark surroundings	A	20-30-50
Simple orientation for short temporary visits	B	50-75-100
Working spaces where visual tasks are occasionally performed	C	100-150-200
Performance of visual tasks of high contrast or large size	D	200-300-500
Performance of visual tasks of medium contrast or small size	E	500-750-1000
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000
Performance of visual tasks of low contrast or very small size over a prolonged period	G	2000-3000-5000
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000
Performance of very special visual tasks of extremely low contrast	I	10000-15000-20000

5.10 HVAC System

- Air conditioning and HVAC systems are one of the major energy guzzlers in not only process industries but also commercial and residential buildings.
- Energy consumption in Air conditioning and HVAC systems is subjected to some related factors such as
  - Load changes
  - Seasonal variations
  - Operation and maintenance
  - Ambient conditions, etc
- Therefore, detailed consideration of all these factors becomes important while evaluating the performance of Air conditioning and HVAC systems.
- **Purpose:** Verify the performance of refrigeration systems.
- **Strategy:** Measure the net cooling capacity and total energy needs.
- **Objectives**
  - Predict the energy consumption under real operating conditions
  - Comparing the performance to its design conditions.
- **Preparatory recommendations**
  - Set up the steady state conditions.
  - Take at least three sets of data at the minimum interval of 5 minutes.

  - Take test readings simultaneously to avoid or minimize the transient effect.

5.10.1 Performance Terms in Air Conditioning and HVAC Systems

It is important to be familiar with the performance terms for the understanding the concept. Following are the key terms with respect to performance terms of Air conditioning and HVAC systems.

(a) Tons of refrigeration (abbreviated as TR)

- TR is an important unit of refrigeration capacity. Tons of refrigeration or Ton simply indicates the capacity or size of the refrigeration plant.
- Actually, it is defined as the amount of heat removal required to make 1 short ton (≈ 907.185 kgs) of ice in 24 hours from water at 0^0.
- 1 TR ≈ 3023.95 kcal/h or 3516.85 W or 12,000 Btu/h

(b) Net refrigeration capacity

- Net refrigeration capacity = (Mass flow rate of evaporator water) x (Enthalpy of water entering the cooler – Enthalpy of water leaving the cooler)
- Units: kCal/h, TR.

(c) kW/Ton rating

- kW/Ton rating is an indicator of efficiency.
- It is the ratio of actual input power fed to the compressor motor (kW) to Tons of cooling produced (Ton).
- It is simply kilowatts consumed per ton.
- Lower the kW/Ton better the efficiency.

(d) Coefficient of performance (abbreviated as COP)

- It is a measure of chiller efficiency.
- For normal industrial use, Coefficient of performance is defined as the ratio of obtained cooling to the input electric power.

$$\text{Coefficient of Power (COP)} = \frac{\text{Cooling effect (in kW)}}{\text{Power input to compressor (in kW)}}$$

- Here, cooling effect is nothing but the difference between the enthalpies at the evaporator and expressed in kW.

(e) Energy Efficiency ratio (abbreviated as EER)

- It is a measure of performance especially for small capacity chillers and rooftop models unlike kW/Ton for higher capacity units.
- EER is the ratio of cooling capacity of the chiller (Btu/h) to the fed input power (Watts) under full load conditions.
- Higher EER is an indication of better efficiency of the unit.

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- American Refrigeration Institute has provided the mathematical interrelations between key energy efficiency performance terms as follows. These are used in the calculation of performance.

Table 5.10.1: Relation between energy efficiency parameters

COP = 0.293 EER
kW / Ton = 12 / EER
kW / Ton = 3.516 / COP
EER = 3.413 COP
EER = 12 / (kW/Ton)
COP = 3.516 / (kW/Ton)

5.10.2 Performance Assessment

(a) Determine the Net refrigeration capacity

- The net refrigeration capacity (in Tons) is determined by,

$$\textbf{Net refrigeration capacity (TR)} = \frac{m \times C_p \times (t_{in} - t_{out})}{3024}$$

Where,

m – Mass flow rate of water (in kg/hr)

C_p – Specific heat of the water (in kcal/kg ^{0}C)

t_{in} – temperature of chilled water at the evaporator inlet (in ^{0}C)

t_{out} – temperature of chilled water at the evaporator outlet (in ^{0}C)

- The numerator in above equation is heat removed from the chilled water. It is the product of flow rate, temperature difference between entering and leaving water and specific heat of water at the evaporator.
- Therefore, it is necessary to measure all these three parameters.
- Online flow meter or ultrasonic flow meter gives flow rate of water.

(b) Measurement of Compressor Power

- The power consumed by compressor motor is calculated by,

$$\textbf{Compressor Power (kW)} = \sqrt{3} \times V \times I \times \text{Cos}\,\phi$$

- Power analyzer gives the direct readout of the compressor power.
- If it not available, simply it can be calculated by using abovementioned formula.
- In this case, online ammeter or tong tester is required for the current measurement and value of the power factor is considered as 0.9.

(c) Performance calculations

- Either of Coefficient of performance (COP), Energy Efficiency Ratio (EER), Power per Ton is used to demonstrate the energy efficiency of the chiller. They are expressed as follows

$$\text{Coefficient of Power (COP)} = \frac{\text{Cooling effect (in kW)}}{\text{Power input to compressor (in kW)}}$$

$$\text{Energy efficiency ratio (EER)} = \frac{\text{Cooling effect (in kW)}}{\text{Power input (in kW)}}$$

$$\text{Power per turn (kW/Ton)} = \frac{\text{Power input (in kW)}}{\text{cooling effect (in Tons)}}$$

Now,

(i) From the measurements in step (a) and (b),

(i) $$\text{(kW/Ton)} = \frac{\text{Measured compressor power (in kW)}}{\text{Net refrigeration capacity (in Tons)}}$$

Using the relations mentioned in Table calculate COP and EER.

(ii) $$\text{Coefficient of Power (COP)} = \frac{3.516}{\frac{\text{kW}}{\text{Ton}}\text{ rating}}$$

(iii) $$\text{Energy efficiency ratio (EER)} = \frac{12}{\frac{\text{kW}}{\text{Ton}}\text{ rating}}$$

(d) Assessment of Air Conditioning System

For air conditioning units, the refrigeration load in TR is assessed as,

$$\text{(TR)} = \frac{m\,(h_{in} - h_{out})}{4.18 \times 3024}$$

Where,

m – Mass flow rate of air (in kg/hr)

h_{in} – Enthalpy of inlet air (in kJ/kg)

h_{out} – Enthalpy of outlet air (in kJ/kg)

- In case of air conditioning system, airflow is handled at the fan coil units (FCU) of air handling units (AHU).
- Anemometer does the airflow measurement at AHU
- Measurement of dry bulb and wet bulb temperature is done at the inlet and outlet of the fan coil units (FCU) or air handling units (AHU).
- Heat content of the inlet and outlet air at the FCU or AHU (i.e enthalpy) can be find out using psychometric chart.

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Determination of Net Refrigeration Capacity	• Net Refrigeration Capacity (TR) = $m \times c_p \times (t_{in} - t_{out}) / 3024$
Measurement of compressor Power	• Power (kW) = $\sqrt{3} \times V \times I \times \cos\phi$ • Power analyser directly give reading in kW unless measure current by online ammeter or tong tester and consider value of power factor 0.9
Performance calculations	• COP = Refrigeration effect (in kW) / input power (in kW) • EER= Refrigeration effect (in Btu/h) / input power (in W) • kW/Ton= input power (in kW) / Refrigeration effect (in Ton)
Performance evaluation of AC system	• Heat Load (TR) = $m \times (h_{in} - h_{out}) / (4.18 \times 3024)$

5.10.3 Various Measurements

At evaporator (in Refrigeration systems)	At fan coil units (FCU) or air handling units (AHU) (in AC systems)	At Compressor
Temperature of entering water (t_{in} °C)	Enthalpy of entering air (h_{in} kJ/kg)	Electrical power input to compressor motor (P kW)
Temperature of leaving water (t_{out} °C)	Enthalpy of leaving air (h_{out} kJ/kg)	–
Mass flow rate of chilled water (m kg/hr)	Mass flow rate of air (m kg/hr)	–
Drop in water pressure between inlet and outlet	–	–

Review Questions

Q. 1 Discuss various features of Energy Conservation Act 2001.

Q. 2 Write a note on ECBC 2007.

Q. 3 Define and explain the concept of energy audit.

Q. 4 State and explain the types of energy audit.

Q. 5 Explain the energy audit methodology in detail.

Q. 6 State the various costs involved in total energy bill of industry. What is the significance of understanding the involved energy costs.

Q. 7 Write a detailed note on Benchmarking in the process of energy audit.

Q. 8 What is the general course of action to maximize the efficiency.

Q. 9 State various instruments (with their function) that are used in carrying out the energy audit

Q. 10 Write a brief note on "Various motor testing standards".

Q. 11 State and explain various methods of motor testing.

Q. 12 What are the various methods of determining the motor loading.

Q. 13 State and explain the key factors on which successful implementation of the VSD depend.

Q. 14 Describe the procedure for assessment of the existing lighting system in the premises.

Q. 15 State any four places with required level of luminance.

Q. 16 Explain the key performance term of HVAC.

Q. 17 Write a detailed note on performance assessment of HVAC.

Q. 18 State the objectives of energy audit and explain its need.

Q. 19 State and explain various phases of energy audit.

Q. 20 Describe the steps to carry out energy audit in a small scale industry.

Q. 21 Discuss any energy audit case study. (Eg. Sugar/Cement/Paper industries/municipal corporation/Educational institute)

5.11 University Questions and Answers

May 2016

Q. 1(c) Explain difference between conventional choke and electronics choke. *(Ans. : Refer section 5.9)* **(5 Marks)**

Q. 2(a) Explain Benchmarking and its types. *(Ans. : Refer Section 5.5.3)* **(10 Marks)**

Q. 3(b) Define energy audit. Explain its types in details. *(Ans. : Refer Section 5.4)* **(10 Marks)**

Q. 4(b) Explain fuel and energy substitution. *(Ans. : Refer Section 5.5.5)* **(10 Marks)**

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UNIT VI

CHAPTER 6

Energy Efficient Technologies, Energy Efficient System Design

Syllabus

Energy Efficient Technologies

Maximum Demand controllers, Automatic Power Factor Controllers, Energy Efficient Motors, Soft starters, Variable Speed Drives, Energy Efficient Transformer. Energy saving potential of each technology.

Energy Efficient System Design

Lighting System; Use of Energy Management system (EMS) and Building Management System (BMS).

Objectives

After studying the chapter you will be able to

- Understand maximum demand controller.
- Know the automatic power factor controller
- Understand energy efficient motor.
- Working and theoretical aspects of energy efficient transformer.
- Understand theoretical concepts related to energy efficient motors.
- Understand working energy management system
- Know the building management systems

Part I : Energy Efficient Technologies

6.1 Introduction

- Reducing the energy intensity without affecting the output is nothing but energy efficiency.
- Energy efficiency is a way of controlling the growth of energy consumption in the facility.

- Obviously, energy efficiency come up with the energy conservation hence it is often promoted as an integral part of strategies for energy conservation.
- Use of energy efficient technologies enables the system to deliver the more output for the same energy input or same output for less energy input.
- Use of energy efficient equipments or technology at proper locations in electrical power system not only reduces the strain on environment but also pulls down the electricity expenses.
- Scope for achieving energy efficiency in electrical power system has been identified mainly at
  - Residential as well as commercial lighting that contributes to significant energy usage.
  - Motor loads in industrial sector.
  - Apart from these, transmission and distribution sector which is not actually a load but consumes energy in the form of losses.
- Use of devices such as occupancy sensors/motion detectors, dimmers or intelligent centralized control equipment leads to noticeable reduction in energy usage as it encourages use only according to necessary sufficient intensity and not when spaces unoccupied.
- Control of maximum demand and kVAR in the transmission and distribution system can be achieved by the installation of Maximum Demand Controller and kVAR Controllers.
- Advanced starters and power factor controllers with electrical motors achieve better energy conservation in industrial sector.

6.2 Maximum Demand Controller

MU - May 2016

- The charges that non domestic or high tension power user pay for the consumption includes,
  - Usual charge per unit for number of units consumed and
  - In addition Maximum Demand Charge.
- The basis for this maximum demand charge is the peak amount of power demand over certain duration of time.
- Maximum demand charge cover large part of total bill and it may be based on one separate slot of high power use.
- Loads like electrical machines draw larger currents while starting hence causes more consumption of energy during their start.
- Such heavy currents at start of the motive loads leads to increased demand at that time.
- In an industrial plant, maximum demand may shoot up if such loads
  - Start simultaneously or
  - Start in few minutes of each other.
- Occurrence of this condition in the same metering slot of time will register higher maximum demand for that plant.
- To avoid the same remedial measures may be,
  - Either starting the motors slowly or lowering the load one after another in interval of an hour.
  - Certain value of the load can be set as reference. Sensing the rise in load, switch it off after reaching the set value.

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- Maximum Demand Controller performs the latter work.
- Maximum Demand Controller keeps the track of Plant demand and compares it with reference value.
- Loads are prioritized as essential and non essential. Non essential ones are switched off as demand exceeds the set point.

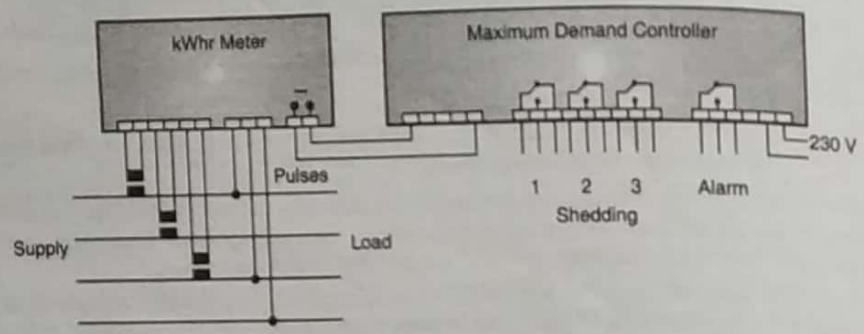

Fig. 6.1.1 : Connection Diagram of Maximum Demand Controller

- Maximum demand controller is installed in the closest vicinity of the Trivector meter for billing relevant monitoring.
- A kWh transducer placed on user's electrical supply produces a pulse for every consumption slot of 0.1 kWh.
- Maximum demand controller keeps the accounts of these pulses and sums it up to a running total.
- After adding up pulses over specific duration (say 15 minutes), previous pulses for the same duration is discarded.
- In this way, record of average power used for those 15 minutes is obtained and shown on a window.
- Similarly, average power for 30 minutes or 60 minutes can also be recorded if required and shown on respective windows.
- The maximum demand controller checks the recorded running average with the set reference load value.
- circuits As soon as the recorded value overtakes the reference value, a set of relays operate.
- The output relays are connected to the load control.
- Non-critical load is disconnected from the supply in a logical sequence by using relay contacts and essential loads are allowed to remain in. This keeps the overall load in a predetermined limit.
- Relay contacts in connection diagram 6.1.1 shows the position before shedding.
- Relay 1 has the lowest priority, relay 2 next highest and relay 3 operates when set reference is exceeded.
- When the situation occurs where cutting off the load is required, relay 1 is the first to operate which controls unimportant load. Relay 2 controls the loads of slightly higher priority.
- Relay 3 connects the loads of highest priority.
- Excessive operation is avoided by providing small amount of hysteresis.
- Shed 3, Shed 2, Shed 1 is an indication of operation of respective relay.

- Sequence according to priority of loads to be disconnected is predefined by user and programmed by both user and supplier of the controller.
- Load management (starting and stopping) of the plant equipments depends on the desired load profile.
- This unit also records peak value of the running average load to date and intimates every time it reach the highest value by alarm or visual display.

6.3 Automatic Power Factor Controller

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- In electrical power systems, power factor control has long been accepted as an important step to energy conservation.
- Capacitors are switched in and out of the system according to need of VAR compensation.
- If properly applied and controlled (possibly automatic) capacitance improve performance of distribution network as it provides reactive current locally and offers the advantage of
  - Lower losses
  - Improved line voltage
  - Reduced utility penalty hence lessened billing charges.
- Automatic power factor control may be achieved using relay / microprocessor / microcontroller.
- Most popular methods of control in automatic power factor controlling are :
  - Voltage control
  - KVAR control
- KVAR sensitive controls are recommended where voltage level is closely regulated and not possible to use as a control variable.

6.3.1 Voltage Control

- Switched capacitors are implemented at the points where voltage reduces as result of circuit load increase.
- At such points only voltage is the parameter which can be used as a source of intelligence.
- Generally, they are applied when voltage drop of 4% to 5 % is caused with increasing load.
- Another type of voltage control is independent of load cycle is at substation.
- At the places like substation, voltage is a factor of prime importance, as it needs to be maintained at a particular level.
- Therefore, voltage is the most commonly observed parameter over here.
- During conditions like light loads or low supply voltage, these capacitors may give leading power factor.

6.3.2 kVAr Controller

- kVAr controllers are used where voltage is not available as a control variable.
- The capacitor is switched as a response to change in power factor due to change in system loading.
- kVAr control can also avoid penalty due to low power factor as it adds capacitors in as soon as p.f. starts to decrease below the desired value.

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- kVAr controller needs two inputs viz. current and voltage from the incoming feeder.
- This is fed to p.f. correction mechanism. The correction mechanism can be based on either microprocessor or relay.

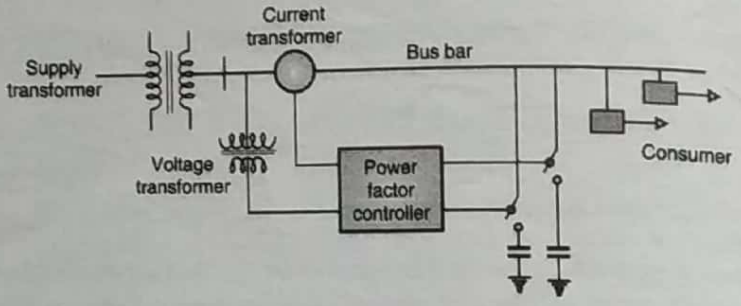

Fig. 6.3.1 : kVAr controller scheme

- As can be seen in above Fig.6.3.1 reactive power compensation scheme is located at entrance of the facility, which offsets the inductive loading (lagging p.f.)
- kVAr controller in general includes :
  - Switched capacitor units
  - Intelligent control unit
  - CT and PT (to sense the current and voltage).
- Mostly capacitor banks consist of 3 to 9 capacitors connected in 3 ϕ grounded star, ungrounded star or delta.
- Switched capacitor banks are preferred over fixed banks as it switches capacitor units on and off to meet the changing load condition.
- Following Fig. 6.3.2 shows an example kVAr demand over a period of 24 hours.

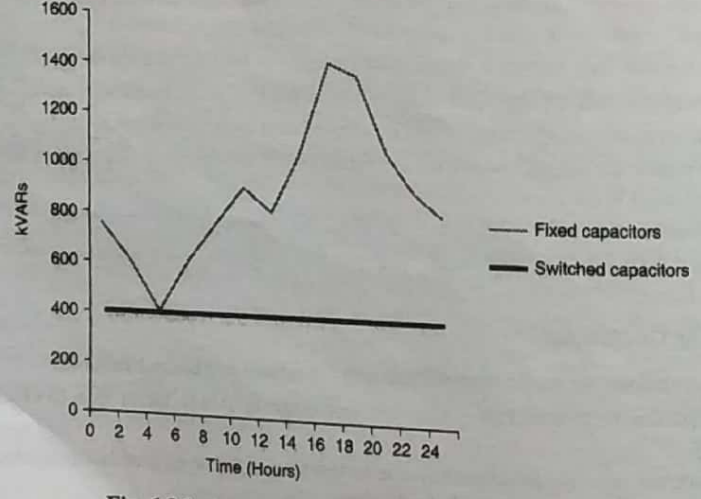

Fig. 6.3.2 : kVAr demand over and 24 hours graph

- This curve can be simply determined by recording kVAr meter or calculated by kW and p.f. measurement.
- The fixed banks satisfy the base kVAr demand and switched capacitors meet the inductive kVAr peak during heavy load slot.

(a) Control

- Controller Senses Voltage and current and uses it either directly or in terms of derived parameters like p.f. to compare against a threshold.
- Generally power factor transducer is employed inside which p.f. is measured and converts it into a DC voltage.
- This voltage is compared with a reference voltage which is calibrated in terms of p.f. and can be set by knob.
- When p.f. falls below the target, the capacitor are sequentially switched.
- The capacitors are controlled by relay.
- This relay is a brain of control circuit as it controls the P.F by sending signals to on or off the capacitors.

(b) Calculation of Required kVAr

- In order to calculate the capacitive kVAr necessary to correct to a new higher power factor, inductive kVAr of the corrected P.F. ($P.F._{new}$) is subtracted from the existing P.F. ($P.F._{old}$).
- The difference is the capacitive kVAr to be added to the system.

$$\mathbf{kVAr = kW \times [Tan\ (Cos^{-1}\ P.F._{old}) - Tan\ (Cos^{-1}\ P.F._{new})]}$$

Where,

kW – the system kilowatt load

kVAr – amount of capacitive kilowatt to be added.

- All capacitor units of same rating and should be ON or OFF in a linear sequences only.
- A dead band range of phase angle is defined over which relay doesn't respond in order to avoid hunting due to over correction.
- When load current is very low all capacitors are switched off one by one in a sequence.
- Rating of capacitance to be added at each step is decided by intelligent power factor controller (IPFC) during the first hour of its operation.
- These are stored in memory and based on these measurements most appropriate switching of capacitor is performed by IPFC.

6.4 Energy Efficient Motors

- In the industrial and commercial sector, electrical motors have been significantly contributing to the major of the energy consumption.
- 43 % to 46 % of the world energy consumption and near about 70 % of total energy consumption of the industry is due to motor and motor drives.

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- Inefficient motors not only causes wastage of electrical energy but also more operational costs.
- Most of the electricity to run these motors is generated from non renewable energy plants which also has an incremental effect on green house gases.
- So economic as well as environmental aspects necessitates the energy efficiency in electrical motors.
- Near about shares of electrical energy use by motors in various sectors of are as follows :

Table 6.4.1

Sector	Share (in %)	Applications
Industrial	70	Processes and Material Handling Equipments
Commercial	38	Mainly HVAC
Agricultural	25	Agriculture Pumps and Fans
Residential	22	Refrigerators/HVAC
Transport	60	Railways

- Penetration of motors in various sectors of energy use as given in above table brings in notice the scope for Energy Conservation in motors.
- Energy efficient motors are motors in which improvements in the design are assimilated so as to increase the efficiency more than the standard motor.
- Design improvements in Energy Efficient Motors mainly target reduction in inherent motor losses.
- Improvement in efficiency is very obvious on reducing the motor losses.
- Each loss is addressed specifically by adopting some measures as follows
- **Stator Cu loss :**
  - Selection of a proper size of the copper conductor so as to reduce its resistance.
  - Mostly the copper cross section of winding wires are preferred to increase which decreases resistance and hence I^2R losses.
- **Rotor Cu losses**
  - Increasing the section of rotor bars and end rings, rotor copper losses can be reduced though weight increase.
  - Use of copper conductors (instead of usually used Aluminium) in rotor causes less winding resistance comparatively.
  - Synchronous speed operation of motor also reduces I^2R loss.
- **Core losses**
  - To reduce Hysteresis loss use of low loss grade silicon steel, modest increase in stator and rotor core length.
  - To reduce eddy current use of thinner laminations.
- **Friction and Windage losses**
  - Better fan design is adopted (Proper Diameter)

  - Use of improved and proper bearings.
  - Improvement in aerodynamic design of rotor and facilitation of airflow.
- **Stray load losses**

  These can be reduced by better electromagnetic design of slots and windings by careful selection of
  - All gap length
  - Number of slots
  - Tooth per slot geometry
- The above mentioned are the modifications incorporated while designing the motor to make it more energy efficient.
- However, energy efficient motor requires the use of
  - Additional materials
  - Better quality materials
  - Improved and advanced manufacturing processes.
- These aspects make energy efficient motor expensive as compared to the standard motors.

6.4.1 Comparison with Conventional Induction Motors

- Energy efficient motors offer wider ranges of capacities.
- Full load efficiencies are found higher than the conventional one by 3% to 7%.

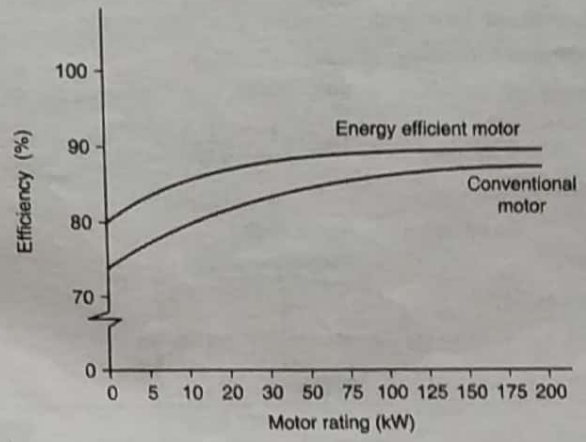

Fig. 6.4.1 : Comparison of Conventional motor and Energy Efficient Motor

- Above Graph shows comparison of efficiencies between convention three phase induction motor and energy efficient motor.
- High efficiency motors run cooler due to lower operating temperature hence ventilation fan can be downsized.
- Voltage fluctuation in input supply has less effect on energy efficient motor.

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- Less noise while operation
- Acceleration to loads with high inertia is better than conventional.
- Cost of energy efficient motor tends to be higher than the standard design.
- Though higher costs are retrieved in the saved operating costs.
- Applications of high intermittent duties are still to be supported by these motors so conventional can be used here.
- Energy efficient motors can't be installed for special applications which demands flame proof operations e.g. fire pumps where conventional motors can.
- Applications of a very low speed are not suitable to use with these motors.
- Another limitation compared to conventional motor is most of the energy efficient motors are suitable for operators of continuous duty cycle.

6.4.2 Caution

- Lower slip of energy efficient motors makes it run at slightly higher speeds.
- These speeds may cause higher flows in applications like centrifugal pumps thus can cause increased power.
- In such cases care is necessary to avoid neutralization of reduced motor losses by increased power.

6.4.3 Energy Saving

Energy saving can be estimated by an example such as,

Replacement of conventional 10kW motor with an energy efficient motor.

Standard efficiency = 83%

Efficiency of energy efficient motor = 89%

$$\text{Power saving} = 10 \times \left(\frac{1}{0.83} - \frac{1}{0.89}\right)$$

For operation of 5000 hours/annum

$$\text{Energy saved} = 0.81 \times 5000$$

$$= 4050 \text{ kWh/annual}$$

If tariff is considered Rs. 4/kWh

$$\text{Cost saving} = \text{Rs. } 16,200/\text{- per annum}$$

6.5 Soft Starters

MU - May 2016

- At the start AC induction motor develops high torque than required at full speed.
- This causes two main issues,
  - Mechanical stress developed due to higher torque transfers this stress to mechanical power transmission system that may cause premature wear and tear
  - Much higher inrush current is drawn than normal that has massive impact on electricity supply charges.
- In AC induction motors, the voltage can also be reduced using a soft starter.

- It is analogous to a primary resistance or a primary reactance starter.
- The current entering the starter equals to the current leaving it.
- They are used with the AC electric motors to decrease the load and torque on the motor during startup. This reduces the mechanical stress on the motor and the shaft.
- It helps to improve the lifespan of the whole system by reducing the electrodynamic stresses on the attached power cables and electrical distribution network.
- Soft starters used for motors have mechanical or electrical devices, or their combination.
- Mechanical soft starter consists of clutches and various types of couplings which transmit torque with the help of a fluid, magnetic forces, or a steel shaft.
- Electrical soft starters can be any control system which momentarily reduce the input voltage or current to decreases the torque.
- Any device that can be used to regulate the motor acceleration by adjusting the applied voltage is termed as soft starter.
- Technically speaking, soft starter controls the applied torque.
- In technical terms, a soft starter is a device that reduces the torque applied to the electric motor.
- It generally consists of solid state devices like thyristors to control the application of supply voltage to the motor.

6.5.1 Working Principle

- The direct relation of torque with current and voltage is the basic principle behind the working of the starter.

Torque α (Starting Current)^2 α (applied voltage)

Therefore, at the motor starting, the reduction in the voltage facilitates the variation in the torque and current.

Basic principle of soft starter

Applied voltage is controlled by controlling the firing angle of the SCRs.

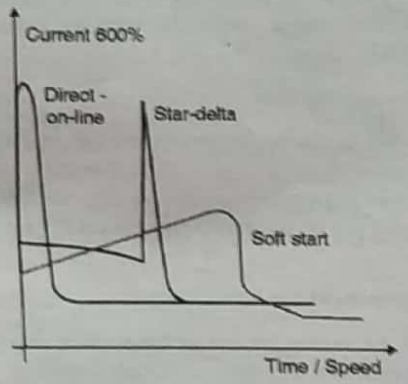

Fig. 6.5.1 : Starting Current profile during starting

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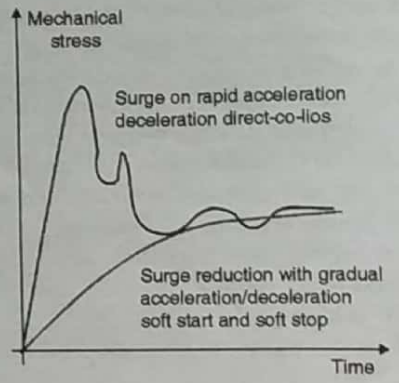
Mechanical stress
Surge on rapid acceleration deceleration direct-co-lios
Surge reduction with gradual acceleration/deceleration soft start and soft stop
Time

Fig. 6.5.2 : Stress profile during starting

- **Soft Stop**
  - Soft stop is the reverse process of soft start.
  - Gradual reduction in the voltage reduces the torque capacity of the motor.
  - No additional costs are required to include soft stop in the soft starter.

6.5.2 Advantages of Soft Starter

- **Smooth starting**

  Torque control offers gradual acceleration of the drive system. It avoids jerks and also extends the life of mechanical components.

- **Reduction in starting current**

  Heavy current at the starting causes weakening of the mechanical, electrical, thermal strength of electrical equipments. Soft starters avoids the same by holding the current back during acceleration.

- **Enhancement of motor starting duty**
  - Use of soft starters moderates the temperature rise in stator windings as well as supply transformer.
  - Soft starters employing microprocessor are also available which offers the software controlled response that economizes energy even at full speeds despite of the extent of the loading.

- **The power factor improvement**

  Soft starters minimize the voltage dependant losses as it automatically regulates the active current components in proportion with the load. It leads to improvement in the power factor.

6.5.3 Applications of Soft starter

- Major application areas of soft starters are :
- Textile industries
- Machine tool applications
- Power sector
- Water supply scheme
- Sugar plants
- Paper and pulp
- Rubber and plastic
- Steel industries (Rolling mills and processing lines)
- Cement industries
- And various process control applications.

6.6 Variable Frequency Drive

6.6.1 What is Variable Frequency Drive ?

- Motor-driven systems are often designed to handle peak loads that have a safety factor. Therefore, when systems are operated for long period at reduced load, the energy efficiency decreases.
- In some motor driven systems, the load varies with time. It is important to size motors such that it will fulfil the maximum demand.
- Adjusting motor speed to match the motor output with load results in energy savings.
- The speed of standard induction motors can be controlled by variation of the frequency of the voltage applied to the motor.
- VFD is one popular member of a category of equipments that is known as adjustable speed drives or variable speed drives.
- Variable speed drives can be electrical or mechanical type, whereas VFDs are purely electrical type.
- Variable speed drives are used to match the motors with the load.
- An electronic variable speed drive (VSD) changes the fixed frequency of the supply (given to induction motor) to a continuously variable frequency to get the adjustable speed.
- Variable frequency drive includes the inverter that changes the frequency of incoming power to a variable frequency and variable voltage to vary the operating speed of a motor. Thus continuous process speed control can be achieved.

  Use of variable frequency drive (VFD) leads large amount of energy saving.

6.6.2 How Does it Work ?

- Induction motor, the important motor of industry, rotates at a fixed speed, which is determined by the frequency of the supply voltage.

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- Alternating current applied to the stator windings produces a rotating magnetic field having synchronous speed.

$$N_s = 120f / P$$

- For a 4-pole motor, with 50 Hz frequency supply

$$N_s = 120 * 50 / 4 = 1500 \text{ rpm}$$

- The rotor of an induction motor always tries to follow this rotating magnetic field.
- Under the load, rotor speed "slips" slightly behind the rotating field.
- Slip speed generates an induced current, and the resulting magnetic field in the rotor, which will produce torque.
- The most effective and energy efficient way of changing the motor speed is by changing the frequency of the applied voltage.
- A VFD converts power frequency (50Hz) to any new frequency between 0 to 300 Hz and sometimes even more.
- The technology includes following units.

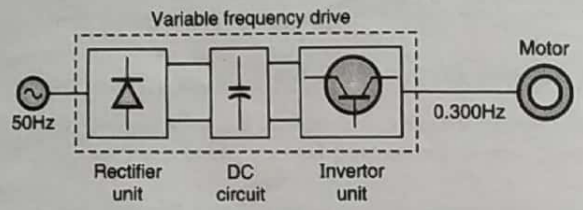

Fig. 6.6.1: VFD Technology

1. Rectifier Unit

- Electrical network feeds AC drive via rectifier.
- A full-wave, solid-state rectifier converts three-phase 50 Hz power to either fixed or adjustable DC voltage. The system may include transformers for step down if higher supply voltages are used.
- Unidirectional Rectifier Unit- Energy is taken from network to accelerate and run the motor.
- Bidirectional Rectifier Unit- Mechanical energy of the motor is processed and supplied back to the electrical network.

2. DC Circuit

- DC circuit is a mediator between rectifier unit and inverter unit.
- It's a storage element to store the electrical energy of rectifier which is to be used by inverter.
- High power capacitors are commonly used to store the energy in this unit.

3. Inverter Unit

- Electrical energy stored at DC circuit is supplied to motor at required frequency through inverter unit.
- It consist of,
  - Electronic Switches
  - Power Transistors or Thyristors
- These produce current and voltage waveform of desired frequency by ON and OFF switching.
- Properly designed inverters and filters minimize distortion to a large extent.
- Converting DC to variable frequency AC is accomplished using an inverter.
- Most currently available inverters use pulse width modulation (PWM) because the output current waveform is closer to a sine wave.
- Power semiconductors switch DC voltage at high speed, producing a series of short-duration pulses of constant amplitude.
- Output voltage is varied by changing the width and polarity of the switched pulses.

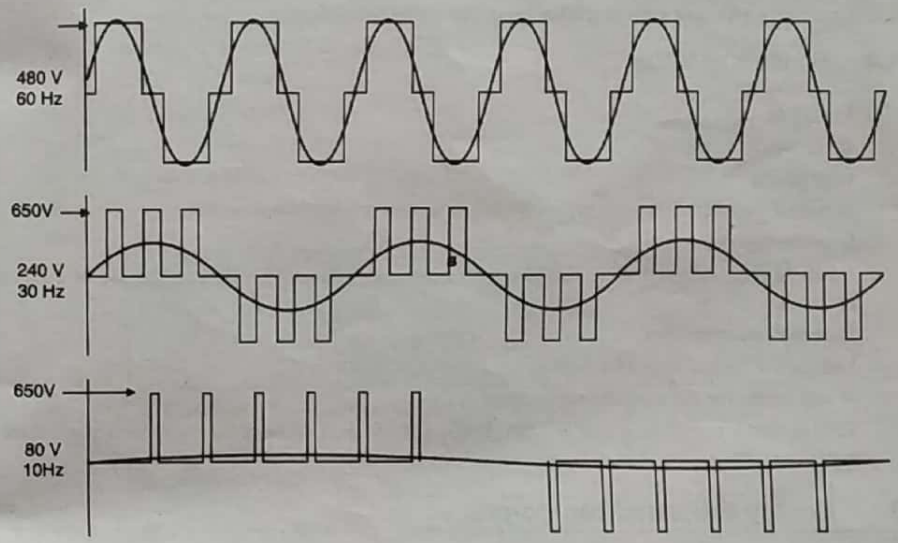

Fig. 6.6.2: Inverter's pulse width modulation output

- Output frequency is adjusted by changing the switching cycle time.
- Point should be noted that output waveform of the VFD is square wave. Though, this wave shape is not that suitable for general distribution system it is more than sufficient for a motor.

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- Reduction in motor frequency can be achieved by slower switching of inverter output transistors.
- Reduction in voltage is must with reduction in frequency so as to maintain V/Z ratio.
- The high-speed switching of a PWM inverter results in less waveform distortion and, therefore, lowers harmonic losses.
- PWM inverter is the best solution because of its low cost, high speed switching etc.

4. **Control system**

- The role of electronic circuit in the control system is to adjust the output voltage or frequency to the desired values on receiving feedback from the driven motor.
- The output voltage is controlled to maintain a constant V/F ratio.
- Complex control functions may be present in the controllers.

6.6.3 Applications

- Complex and difficult environments such as water and wastewater processing.
- Tunnel boring, oil drilling platform, mining.
- Motor-driven centrifugal pumps, fans and blowers.
- Conveyers, machine tools and other production-line equipment

6.6.4 Benefits of VFDs

- Energy savings
- Better process control
- Cost saving
- Increased productivity
- Improved product quality
- It can be used for control of process temperature, pressure or flow without the use of a separate controller.
- Less maintenance costs.
- Longer life for bearings and motors.
- A soft starter for the motor is not required.
- VFD to limits torque to a user-selected level. Therefore, it protects the equipment when there is excessive torque.

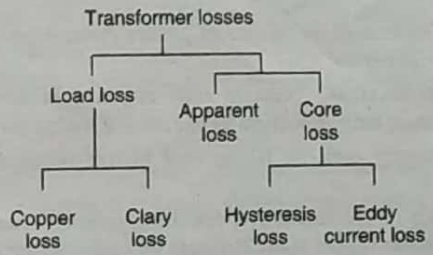
6.7 Energy Efficient Transformer

- The total of transformers used in transmission and distribution system, supplying power to all class of consumer industrial, commercial domestic and rural is very large.
- Even small amount of losses in every transformer aggregately contributes a significant energy loss as well as global warming and climate change.
- Thus, even small positive change in transformer efficiency will lead to remarkable reduction in generation capacity requirement and hence green house gases emission.

- Energy efficiency in transformer is nothing but reduction in energy losses related with transformer operation in electrical power system.

6.7.1 Efficiency Opportunities and Approaches

- Various losses that occur in transformers are the energy efficiency opportunities.



- Two components that mainly contribute, rather transformer losses consist of core loss and copper loss.
- Measures related to the material and design so as to improve efficiency of the transformer are as follows :
  - Design such as it will have lower operating temperatures.
  - Use of magnetic materials with low losses
  - Improve core window fill factor
  - Reduce stray losses.
  - Minimize hot spots in coils
  - Proper distribution of material
  - Improved methods of cooling and effective medium.
- Remedial approaches to address the Iron loss, copper loss and eddy current losses in transformer are;

Type of Loss	Remedial approaches
Iron loss	Use of better core material. • CRGO • Amorphous Metal
Copper loss	Greater diameter of conductor material. Winding material with lesser resistivity
Eddy current loss	Laminated cores

6.7.1.1 Core Material (to Minimize Iron Loss)

- Important materials in the manufacturing of core are CRGO and Amorphous metal.
- Amorphous core has 25% more losses than CRGO. This is available in very thin form and gives high permeability which leads too much less losses compared to CRGO.
- When higher flux density is used in CRGO though it causes higher core losses, less copper is required hence reduced copper losses.

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- Amorphous core causes losses 30% less as compared to conventional steel cores but it's an expensive option.
- Silicon steel is an alternative less costly core material having losses greater than amorphous iron and less than standard carbon steel.

6.7.1.2 Conductor (to Minimize Copper Loss)

- Copper losses can be minimized by the use of greater diameter of conductor wire and winding material with lesser resistivity.
- Casually choosing the thickness, increases eddy currents. In this regard, sectionalisation is preferred in order to reduce radial thickness to minimize the eddy currents.
- Winding turns are properly built up taking care of transportation and mechanical strength, required insulation.
- Use of copper in place of aluminum reduces the resistivity. Current flowing through wires encounters less resistance in copper than aluminum for same diameter.

- So use of copper causes,
  - Less electrical losses which produces undesirable heat.
  - Reduced transformer full load losses and allow smaller cores.
  - Reduced no load losses.

6.7.1.3 Core Laminations (to Minimize Eddy Current Loss)

- Laminations mitigate the eddy currents.
- Iron core is formed by laminations dipped in insulating varnish.
- Sliced core offers very less width to circulate eddy currents.
- Silicon steel sheets to replace with solid core break up the eddy current path without incrementing reluctance of magnetic path.

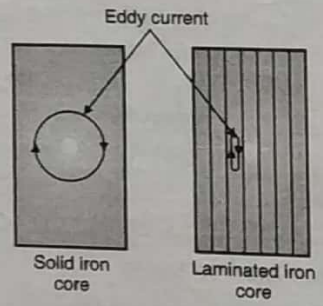

Fig. 6.7.1

- In addition to increased efficiency, above approaches benefits in,
  - Minimized unit dimensions
  - Minimized transformer heating which reduces need of extra cooling and insulation.

  - Minimized noise
  - Increased Insulation life
  - Withstand harmonic loads.

6.7.2 Amorphous Transformers

- Conventional transformer use the core of silicon steel laminations with an almost uniform crystalline structure i.e. CRGO.
- Amorphous transformers employ the core of amorphous steel, which has lower hysteresis losses.

Amorphous alloy

- Metal have crystalline structure with an neat arrangement of atoms.
- When a metal in a liquid form at high temperature is rapidly cooled, it retains its liquid structure on solidification.
- It results in a non-crystalline alloy which contains randomly arranged crystals, termed as amorphous alloy
- Amorphous alloys have superior strength and better electrical characteristics but needs advanced machining techniques.
- Amorphous transformer consists magnetic core of ferromagnetic amorphous metal.
- Quintessentially used material in metglass.
- Met glass alloy = Iron + Boron + Silicon + Phosphorous.
- It's used in the form sheets of near about 25μm as shown in Fig. 6.7.2.
- These material offers the advantages
  - High magnetizability
  - Less affected by external magnetic field or better coercivity.
  - Greater electrical resistance.

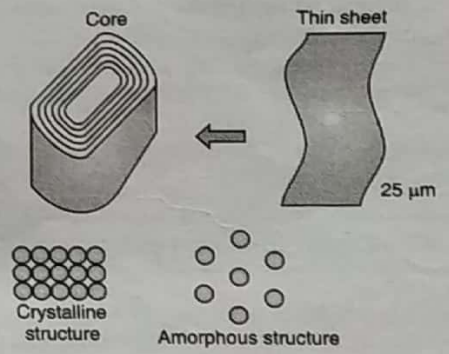

Fig. 6.7.2

- Fig. 6.7.2 shows a typical core made up of layers of thin ribbons or sheets of amorphous metal.
- Due to this foiled structure, less induction of eddy currents when exposes to alternating magnetic field.

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- In the manufacturing itself amorphous metal gives metal as a very thin ribbon like continuous strip having thickness much lesser to that of standard silicon steel sheets.
- This causes near about 40% less eddy current loss to that caused by silicon steel lamination.

6.7.2.1 Advantages

- Easier to magnetize and demagnetize.
- **Less no load losses**

  No load losses are 20 to 30% less as compared to conventional silicon steel sheet transformer which keeps occurring for lifetime despite of transformer load.
- **Easy repair**

  Its modular construction makes repair easy and fast.
- **Better overload capacity**

  Over load capacity is better as heat generation is less due to less loss and obviously less effect on aging of insulation.
- **Better distribution efficiency**
- Distribution efficiency increases due to reduced no load loss. This can save monetary investments in generation capacity concern.
- **Environmental care taker**

  Also contributes to protection of environment as it lowers the emission of CO_2 and SO_2 because of reduced generation need.

6.7.2.2 Disadvantages

- The final product in the ribbon form is brittle and narrow continuous. To cut this into section is a tough job. Hence, it is preferred to manufacture a hollow cylindrical wound core of single continuous strip.
- Larger cross section of core is required for same power and rating of silicon steel lamination. This is due to less useable peak magnetic field intensity in amorphous core. Also causes added weight and size.
- With large size of core longer winding conductors are obvious which causes increased load losses.

Part II : Energy Efficient System Design

- An energy management system (EMS) is a system, which includes computer-aided toolbox that allows the centralized monitoring and control of energy consumption in the facility.
- Energy management system (EMS) and Building management system (BMS) or Building automation system (BAS) are equivalent and often used interchangeably. Their distinction completely depends on the context.

- A building management system (BMS) particularly does centralized control of the equipments in a building such as HVAC, fire alarm, etc.
- Energy Management system (EMS) is the term used for an automated electric utility grids and it includes comprehensive and superior monitoring and control systems as compared to BMS or BAS.
- However, some systems can be arranged in the EMS in order to control building systems in addition to energy management. Also, BMS or BAS can be provided with add on technologies to perform energy management.

6.8 Energy Management System

MU - May 2016

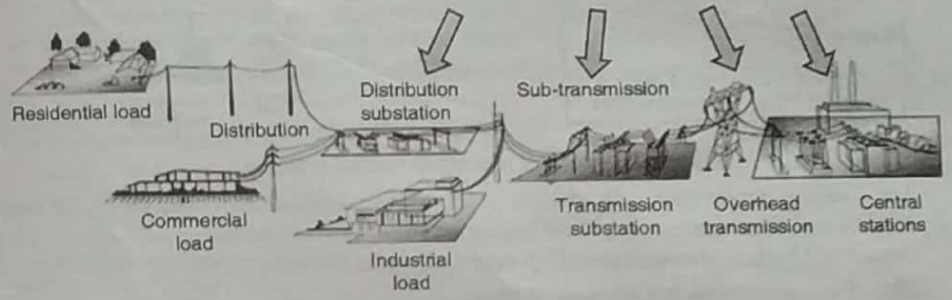

Fig. 6.8.1 Power Network

- Operators of modern utility use a system of computer aided tools called as Energy Management System in order to monitor, control and optimize the performance of generation, transmission and distribution.
- EMS is related to the real time monitoring, operation and control of a power system. EMS consists of both hardware and software.
- **Hardware part of EMS**: RTU, Intelligent Electronic Device (IED), Protection, Computer networking, .etc.
- **Software part of EMS**: Application programs for network analysis of power systems.
- The monitor and control functions are known as Supervisory Control and Data Acquisition (SCADA), followed by several on-line application functions.
- The scope of EMS may span from a load dispatch center to a group of power networks. Most of these energy management systems also provide decision-making facilities for operator in the operation and control in real time.
- SCADA is referred to the centralized control and monitoring system out of it. This system may be installed in one or more control centers.
- An example of control center structure for large utility can be observed in figure 6.8.2

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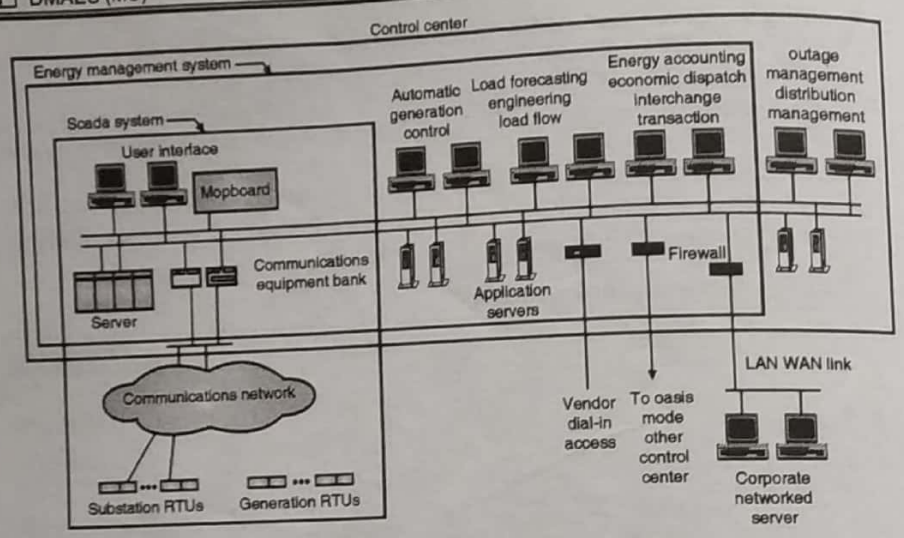

Fig. 6.8.2 : Structure of a utility control centers

- Large utilities render service to multiple (Thousands or even millions) consumers, in such systems regional portions are monitored by many of these control centers.
- Smaller and Rural utilities incorporate subset of equipments as shown.
- Major constituents of the control center include,
  - SCADA system,
  - Energy Management System, and
  - Other application servers and/or workstations.
- Supervisory control and data acquisition (SCADA) systems have been playing a major role in strengthening the utilities to deliver power with reliability and safety by providing them valuable knowledge and capabilities.

Supervisory Control => Remote Control of Field Devices

Data Acquisition => Monitoring of Field Conditions

- A well adopted SCADA system effectively operates the most critical and costly assets of distribution, transmission, and generation of utility.
- Many industries refer the term SCADA quite commonly to a centralized control and monitoring system.
- In electrical utility sector, SCADA deals with basic Control and Monitoring of,
  - Field devices
  - Breakers
  - Switches
  - Re-closures
  - Capacitors and
  - Transformers
- In a SCADA System, as can be observed in the Fig 6.8.2 above. it's major parts are,
  - Data Collection Computers

  - Remote Terminal Units (RTUs)
  - User Interface
  - Communication Channel.
- The location of Data Collection Computers is Control Center and RTUs are installed in the field.
- The information from the power system (substations, lines or feeders) is read through Remote Terminal Units (RTUs); an integral part of SCADA to an EMS or Energy Control Centre (ECC).
- These can monitor and control collectively from anywhere and from thousands of data points.
- In addition, it incorporates a user interface that is monitored all the time.
- This user interface includes a computer display as well as map board that provide a summary of system status.
- The communication channels in a SCADA system perform an important function of transmitting information between Central Computers and RTUs to and fro.
- These channels can be created physically by employing leased lines or dedicated fiber and licensed microwave or unlicensed spread spectrum radio or satellite links are wireless media.
- Energy Management System applications use real-time data such as:
  - Frequency
  - Actual generation
  - Tie-line load flows, and
  - Plant units' controller status to provide system changes.
- Energy Management Software (EMS) is a general term referring to a variety of energy-related software applications which may provide
  - Utility bill tracking
  - Real-time metering and lighting control systems
  - Building simulation and modelling
  - Carbon and sustainability reporting
  - Demand response, and/or energy audits.
- Energy management system is "a system of systems" approach.

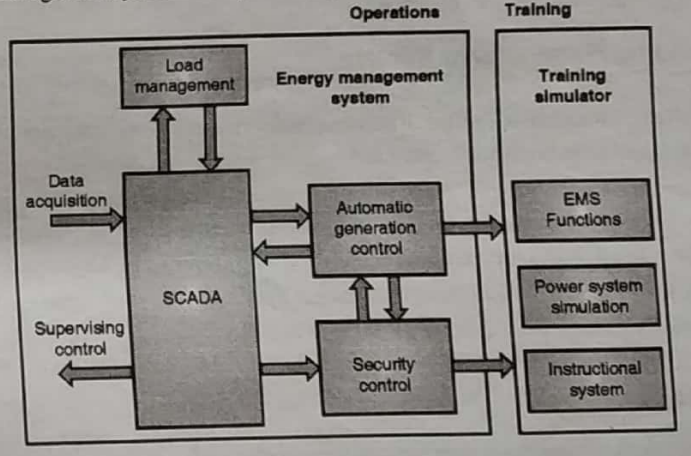

Fig 6.8.3: Energy Management System Applications

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6.8.1 Energy Management System Applications

- **Real time SCADA**
  - It includes the applications to monitor and control the network such as,
    - Data acquisition- Alarms/Events
    - Supervisory control
    - Tagging: Identify the device that should not operate.
    - Control sequences
    - Data logging
    - Trending
- **Automatic Generation and Control**
  - AGC applications provides the functions required for dispatch and closed loop digital control of multiple generators to maintain frequency, power interchange and power allocation among generators at scheduled and economic values.
    - Unit commitment
    - Fuel scheduling
    - Transaction evaluation
    - Security constrained dispatch
    - Production cost calculation
- **Load management**
  - System Load forecast
  - Load shedding applications.
- **Transmission security management**
  - TSM applications provide advanced applications to do the analysis of transmission network to optimize it.
    - Transmission loss minimization

6.9 Building Management System

- A **Building Management System** (BMS) is control system having computer aided tools and installed in buildings to control, monitor and optimize services in a facility.
- These services are mechanical, electrical or electromechanical, which includes power systems, heating, ventilation, air-conditioning, physical access control, pumping stations, elevators and lights fire systems and security systems.
- Recently BMS is also termed Building Automation System (BAS)
- Very basic BMS consists of
  - Hardware
  - Software
  - A server with a database Smart sensor connected to an Internet-capable network.

- Smart sensors around the building gather data and send it to the BMS, where it is stored in a database.
- When any reported data is observed to be violating the defined limit, the BMS takes an action.
- Let us consider an example of IT industry if temperature in a server rack is increasing further the acceptable limit, BMS will give the alarming signal.
- Depending on the system, BMS software can be installed as a standalone application or it can be integrated with other monitoring programs.
- An Example of Building Management System from perspective of lighting control has been discussed in the next section.
- Though it's mainly designed for the lighting, it can be employed for HVAC, Service Water Heaters and Motor loads, etc with minor modifications.

6.9.1 Centralized Control Equipment for lighting

- Microprocessor based systems can be used as a solution to manual systems.
- A microprocessor based centralized lighting control system is nothing but a microprocessor based centralized load controller.
- It is desirable that lighting should be ON only if persons are there in the room or intensity should be adjusted according to availability of natural light.

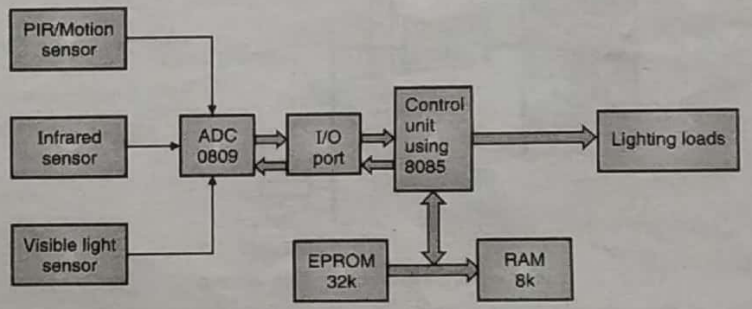

Fig. 6.9.1 : Centralized control equipment using 8085

- Automatic ON/OFF control is either programmed or event initiated.
- Lighting energy is saved by effectively management ON and OFF times.
- It incorporates transducers for detecting presence of person in room i.e. occupancy sensors or motion detectors.
- Central processing unit reads only digital signal hence analog output of the sensors are converted to digital form by ADC.
- Sum of digital data obtained from occupancy sensors is compared with the reference value.

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- If this sum is greater than reference value it's an indication of presence of person of the room and the lights are turned ON.
- Desired value of illuminance to be maintained lies between 135 to 300 Lux.
- The digital data of light sensors are continuously compared with digital equivalent of illuminance range.
- This is observed in the form of look up table to maintain ambient light at a proper level.
- The design works with software written in low level 8085 assembly language program stored in EPROM.
- For off hours, system has a provision of override switches to regain lighting control by building users.

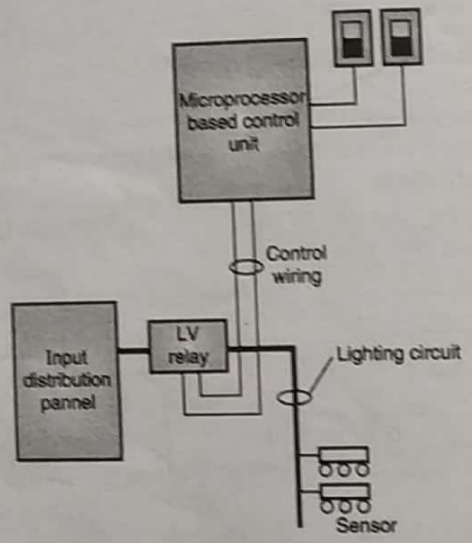

Fig. 6.9.2 : Time scheduling system

- Fig. 6.9.2 shows time scheduling system with following major components.

(a) Central processor

- It can independently control several output channels.
- Single output channel can be assigned to control many lights in a group.

(b) Relays

- Central processor controls these relays.
- These are nothing but electrical switching devices connected to the controlled lighting zones.

(c) Override switches

- Purpose of override switches is to operate parts of lighting system in unscheduled occupancy duration.
- These are the user activated switches and located near the load they effect.

(d) Control wiring

- It connects all components of the system.
- It can be a dedicated wiring or power line carrier.

6.9.2 Microprocessor Based Centralised Load Programmer

- Time oriented, programmable control operates any number of loads from a central resource.
- It can schedule ON/OFF periods for selected loads, allow variation of ambient light for weekends, holidays, etc. a year.
- Entry code is provided to avoid tampering with the program.
- Central controller's keyboard or push button telephones in case of remote purpose are used to enter the lighting control program into system memory.
- Scheduling of load ON and OFF at each of output channel for selected times through a day can be programmed by maintenance personnel.
- For example: While programming for an office it should be written order to switch off the loads after the OUT timing of workers.

6.9.3 BMS applications

- Illumination control
- Electric power control
- Lifts
- Elevators
- Plumbing
- Smoke detector systems
- Fire sprinkler systems
- Access control systems
- Control panel
- Security systems, etc

Review Questions

Q. 1 Discuss maximum demand controller in detail.

Q. 2 Write a note on automatic power factor controller.

Q. 3 Write a detailed note on Energy efficient motor.

Q. 4 Compare energy efficient motor with the conventional induction motor.

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Q. 5 Write a note on Sot starters. State advantages and applications.

Q. 6 What is variable frequency drive? How does it work?

Q. 7 State the benefits and applications of VFDs.

Q. 8 Write a detailed note on energy efficiency transformers.

Q. 9 Explain amorphous transformer. State its advantages and disadvantages.

Q. 10 Write a detailed note on Energy management system (EMS).

Q. 11 Explain the role of SCADA in Energy management system (EMS).

Q. 12 What are the various areas of application of Energy management system (EMS).

Q. 13 Write a detailed note on Building management system (BMS). State its application.

Q. 14 Explain any one example of Building management system (BMS).

6.10 University Questions and Answers

May 2016

Q. 1(d) Explain APFC. *(Ans. : Refer Sections 6.3)* **(5 Marks)**

Q. 1(a) Explain soft starters. *(Ans. : Refer section 6.5)* **(5 Marks)**

Q. 4(a) Explain energy efficient lighting controls in details. *(Ans. : Refer Sections 6.2 and 6.3)* **(10 Marks)**

Q. 6(a) Explain EMS in details. *(Ans. : Refer Section 6.8)* **(10 Marks)**

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